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Edited by

O. M. B. BULMAN, Sc.D, A.R.C.Sc., F.R.S.,

S. R. NOCKOLDS, Ph.D.,

and

W. B. HARLAND, M.A.

assisted by

PROFESSOR W. G. FEARNSIDES, M.A., F.R.S.
PROFESSOR LEONARD HAWKES, D.Sc., F.R.S.
PROFESSOR O. T. JONES, M.A., D.Sc., F.R.S.
PROFESSOR SIR WILLIAM PUGH, O.B.E., D.Sc., F.R.S.
PROFESSOR C. E. TILLEY, Ph.D., F.R.S.

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CONTENTS OF VOLUME XCV, 1958

No. 1 JANUARY–FEBRUARY PAGE

R. NEVES. Upper Carboniferous Plant Spore Assemblages from the *Gastrioceras subcrenatum* Horizon, North Staffordshire . . 1

W. E. NEVILL. A Note on the Occurrence of Coal Measures in Eastern County Limerick, Ireland 20

G. H. FRANCIS. The Amphibolite of Doir'a'Chatha (Durcha), Sutherland 25

N. F. HUGHES. Palaeontological Evidence for the Age of the English Wealden 41

N. J. SNELLING. Further Data on the Petrology of the Saxa Vord Schists of Unst, Shetland Isles 50

D. H. MACKENZIE. The Structure of the Grantown Granite Complex, Morayshire 57

A. HALLAM. A Cambro-Ordovician Fauna from the Hecla Hoek Succession of Ny Friesland, Spitsbergen 71

D. G. JONES. A note on new Namurian Plant localities at the head of the Neath Valley, South Wales 77

CORRESPONDENCE.—A Use for Acetic Acid in the Study of Fossil Sponges, 82 ; On some Turkish Sediments, 83 ; Recent Marine Deposits near Basrah, 84 ; Namurian Stage Names, 85.

REVIEWS.—Glacial and Pleistocene Geology, 86 ; Mio-Pliocene Floras from West-Central Nevada, 87 ; Fossilium Catalogus II : Plantae, 87 ; A Treatise on Limnology, 87 ; Lehrbuch der Tektonischen Geologie, 88.

No. 2 MARCH–APRIL

W. B. HARLAND and M. B. BAYLY. Tectonic Regimes . . . 89

R. TAVENER-SMITH. The Development of the Mid-Zambezi Valley in Northern Rhodesia since Early Karroo Times 105

P. F. HUTCHINS. Devonian Limestone Pebbles in Central Devon . . 119

C. A. COTTON. Alternating Pleistocene Morphogenetic Systems . 125

A. A. DAY. The Pre-Tertiary Geology of the Western Approaches to the English Channel 137

S. MOORBATH, S. R. TAYLOR, and B. G. J. UPTON. Age of Zircon from the Kunait Syenite Complex, South-West Greenland . . . 149

C. L. FORBES, K. A. JOYSEY, and R. G. WEST. On Post-Glacial Pelicans in Britain 153

R. W. HEY. High-level Gravels in and near the Lower Severn Valley . 161

CORRESPONDENCE.—On Some Turkish Rocks, 169 ; Antidunes and Flame Structures, 169 ; Load-cast Structures, 171 ; Igneous Rocks at Gorei, Shilemadu Range, British Somaliland, 172.

REVIEW.—Mesures Gravimétriques et Magnétiques dans la Partie Centrale de l'A.O.F., 174.

PUBLICATIONS RECEIVED.—176.

No. 3 MAY–JUNE PAGE

R. St. J. LAMBERT. A Metamorphic Boundary in the Moine Schists of the Morar and Knoydart Districts of Inverness-shire . . 177

P. STONE and G. M. BROWN. The Quihita-Cunene Layered Gabbroic Intrusion of South-west Angola 195

A. WILLIAMS. Oblique-Slip Faults and Rotated Stress Systems . . 207

D. E. B. BATES and W. SCHWARZACHER. The Geology of the Land between Ekmanfjorden and Dicksonfjorden in Central Vestspitsbergen 219

A. J. SMITH and N. RAST. Sedimentary Dykes in the Dalradian of Scotland 234

I. G. GASS. Ultrabasic Pillow Lavas from Cyprus 241

I. MCDOUGALL and R. GREEN. The Use of Magnetic Measurements for the Study of the Structure of Talus Slopes 252

CORRESPONDENCE.—The Carboniferous Upland Flora, 261.

NOTICE.—University of New England, Armidale, N.S.W., 262.

PUBLICATIONS RECEIVED.—262.

REVIEWS.—Die Geotektonische Entwicklung des Apennin-Systems, 263 ; Studies on Fossil Vertebrates, 263 ; Phreatophytes, 264 ; Fossilium Catalogus II : Plantae, 264.

No. 4 JULY–AUGUST

M. S. RAO. Composite and Multiple Intrusions of Lamlash-Whiting Bay Region, Arran 265

B. E. LEAKE. Composition of Pelites from Connemara, Co. Galway, Ireland 281

A. N. CARTER. Pelagic Foraminifera in the Tertiary of Victoria . 297

C. B. WILSON. The Lower Middle Hecla Hoek Rocks of Ny Friesland 305

H. C. SQUIRRELL. New Occurrences of Fish Remains in the Silurian of the Welsh Borderland 328

T. N. CLIFFORD. A note on kyanite in the Moine Series of Southern Ross-shire, and a review of related rocks in the Northern Highlands of Scotland 333

R. GRADWELL. Post-Tectonic Granite-Gabbro Complexes in Southeastern Queensland 347

CORRESPONDENCE.—The Evolutionary Plexus, 351 ; Development of Lineation in Complex Fold Systems, 351.

No. 5 SEPTEMBER–OCTOBER

B. P. RUXTON. Weathering and Surface Erosion in Granite at the Piedmont Angle, Balos, Sudan 353

D. L. REYNOLDS. Granite : Some Tectonic, Petrological, and Physico-Chemical Aspects 378

F. M. BROADHURST and R. A. HOWIE. On the Occurrence of Ankerite in a Band of Non-Marine Lamellibranchs from the Lancashire Coal Measures 397

I. D. MUIR and C. E. TILLEY. The Compositions of Coexisting Pyroxenes in Metamorphic Assemblages 403

J. G. LAFUSTE. Note on the Structure and Microstructure of *Thecia swinderniana* (Goldf.) 409

PAGE

R. G. S. HUDSON. The Upper Jurassic Faunas of Southern Israel . 415

CORRESPONDENCE.—The Evidence for Cosmic Upward Pull in Mountain and Land Uplift, 426 ; Ultrabasic Pillow Lavas from Cyprus, 436 ; Pelagic Foraminifera in the Tertiary of Victoria, 438 ; Development of Lineation in Complex Fold Systems, 439 ; Derived Ammonites in Basal Cretaceous Conglomerate, 440.

No. 6 NOVEMBER–DECEMBER

G. E. G. WESTERMANN. The Significance of Septa and Sutures in Jurassic Ammonite Systematics 441

A. T. V. ROTHSTEIN. Pyroxenes from the Dawros Peridotite and some comments on their nature 456

D. S. BUIST. The Bostonite of Rudh'a' Chromain, Carsaig, Mull . 463

C. L. FORBES, W. B. HARLAND, and N. F. HUGHES. Palaeontological Evidence for the Age of the Carboniferous and Permian Rocks of Central Vestspitsbergen 465

R. POTONIÉ. Views on Spore Nomenclature 491

J. L. KNILL and D. C. KNILL. Some Discordant Field Structures from the Dalradian of Craignish, Argyll, and Rosguill, Co. Donegal . 497

CORRESPONDENCE.—Picrite, 511 ; Dimensions of Asymmetrical Folds, 511 ; African Erosion Surfaces, 513.

REVIEWS.—Fossil Men : A Textbook of Human Palaeontology, 514 ; Man's Journey through Time : A first step in Physical and Cultural Anthropology, 514.

PUBLICATIONS RECEIVED.—515.

INDEX.—517.

GEOLOGICAL MAGAZINE

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Upper Carboniferous Plant Spore Assemblages from the *Gastrioceras subcrenatum* Horizon, North Staffordshire

By R. NEVES

(PLATES I–III)

ABSTRACT

From a locality in North Staffordshire. Microspore assemblages are described from the Six Inch Mine coal seam, the immediately overlying carbonaceous shales, and the marine shale bed. Marked differences occur within this thin sequence in the proportions of certain genera present; in particular, the dominance of *Florinites* in the marine shales is discussed. Whilst the proportionate numbers of genera vary, the actual species present are more or less the same, though a greater variety exists in the shales. Three new genera and seven new species are described.

INTRODUCTION

THE aim of the work has been to confirm the presence of microspores in carbonaceous shales of Upper Carboniferous age from the North of England, by the use of maceration techniques, and to compare the variety and distribution of spores in shales with assemblages from coals. Workers in palynology concerned with the description of Carboniferous spores have confined their attention mainly to coal seam assemblages. These assemblages, as several authors have observed (Hoffmeister, Staplin, and Malloy, 1955, p. 372), represent a flora of limited ecological association. Consequently in order to determine the overall distribution and range of the various spore types it is necessary to examine a wider range of ecologies, such as may be represented by the spores contained in sediments of all types.

Maceration techniques developed allow the microspores, contained in many carbonaceous shales, to be isolated in a condition that enables description and comparison with those obtained from coals. The following account compares qualitatively and quantitatively the assemblages of spores from a coal seam, a " non-marine " shale, and

a marine shale. The three rock types are in a continuous and restricted vertical sequence and were selected from the same locality in order to reduce the effects of evolutionary changes and to minimize the possibilities of regional variation. The selection of the actual horizon was conditioned by the fact that this work forms part of a broader study of the Namurian and Lower Westphalian spores from North Derbyshire and Staffordshire. The locality chosen was an exposure of the *Gastrioceras subcrenatum* horizon in a stream gully near The Wash (G.R. SK 014662), Quarnford, Staffordshire. The sequence consists of a thick seat earth overlain by a thin coal seam, 1½ to 2 inches; the grey roof shales (18 to 24 inches) yield plant fragments and are succeeded by approximately 6 inches of black carbonaceous shales containing goniatites. The goniatite bearing shales were taken as the true marine deposits whilst the underlying grey shale contained no fossils and is subsequently referred to as " non-marine ". F. W. Cope (1946) correlated the coal seam with the Six Inch Mine of Lancashire and the Pot Clay Coal of Yorkshire. The horizon lies, therefore, at the junction of the Namurian and Westphalian measures in North Staffordshire.

Channel samples were taken from the three rock types and the microspore assemblages obtained were used as the basis for this study.

Previous Work

Relatively few authors have published work on the Namurian plant spores and in particular on spores of this age from argillaceous sediments.

Raistrick (1937), Millott (1939), and Knox (1947) studied microspores of Namurian age in Great Britain during their analysis of assemblages from coal seams only. Full studies were rendered somewhat difficult particularly in the Central English area since the coal-seams there are spasmodic in occurrence and as Millott (1939, p. 320) pointed out, the physical character of the coals creates problems of maceration leading frequently to a poor microspore yield. More recent work by Horst (1955) is contained in an account of the Namurian " Dispersed Spores " from Mahrish-Ostrau and West Upper Silesia, the result of sampling from coals alone. The results from this work were incorporated in the monograph of Potonie and Kremp (1955 and 1956). Hoffmeister, Staplin, and Malloy (1955) published the results of an investigation into plant spores derived both from coals and shales contained within the Mississippian of Illinois and Kentucky. These authors described several new genera and species and discussed the relative abundance of spore types in the various sediments. They noted a great variation in the relative abundance of genera within short vertical ranges though the same genera and

species were generally in common throughout. No particular mention was made of *Florinites* which shows such a marked variation in numbers in the present study.

Maceration Techniques

The treatment of both shale and coal was essentially similar in that the microspores were released from the humic material by oxidation with Schulze solution and subsequent washing with potassium hydroxide solution.

A channel sample of coal was mechanically crushed and macerated with Schulze solution for a period of 12 hours. The residue was washed with 10 per cent potassium hydroxide and distilled water in a sinter glass funnel until the filtrate was colourless. The spore concentrate remaining was pipetted off and mounted in glycerine jelly.

The shales were at first treated in order to remove argillaceous and other mineral matter and to obtain a concentrate of organic residues. For this purpose, shale fragments (approximately ¼ inch square) were immersed in bromine for a period of up to 48 hours, which effectively broke up the shale into a fine aggregate. The bromine was then washed off with distilled water in a pressure-assisted filtration system. The bromine-free material was transferred to a polythene flask and heated in 40 per cent hydrofluoric acid on a water bath for 16 to 20 hours, a time sufficient for the removal of the mineral matter. The acid was decanted off and the mineral-free organic concentrate was then oxidized by Schulze solution for a period of 4 to 6 hours. Thereafter the method described for coal preparation was followed.

The bromine plays an important part in this procedure, which apparently results in a mechanical disintegration of the shale possibly through the accompaniment of mild oxidation of organic and some inorganic constituents. Bromine treatment increased the ease and efficiency with which the hydrofluoric acid attacked the mineral residues to such an extent that slides prepared from the shales so treated contained little or no argillaceous residue. The use of bromine and hydrofluoric acid in this technique has no deleterious action upon the spores themselves. A check was carried out on a sample of coal which had been treated with bromine and hydrofluoric acid prior to oxidation with Schulze solution. Slides prepared from this maceration showed the microspores to be comparable in size and relative abundance to those obtained from the same coal but prepared by the normal method of coal maceration.

Systematic Palaeontology

The system proposed by Potonié and Kremp (1954) for the classification of microspores is used in this paper since it is the most com-

prehensive available at the present time and has the advantage of adequate description and illustration.

All slides are in the collection of the Geology Department, Sheffield University; the locality for all is The Wash, Quarnford, Staffordshire.

Division **Triletes**

Subdivision AZONOTRILETES

Suite LAEVIGATI

Genus *Discernisporites* (type species *D. irregularis*) gen. nov.

Trilete iso- or microscpores, with smooth triangular equatorial outline, sides slightly convex. Rays of the tetrad mark one-half to three-quarters radius of spore body. Folds which frequently accompany the rays often extend to the equatorial margin. A triangular area (? contact area) around the proximal pole is differentiated from the remainder of the exine by nature of its structure or sculpture, which gives the spores of this genus a characteristic zoned appearance. The exine of the distal surface and outer band of the proximal surface is thin and laevigate to infrapunctate or infragranular.

Remarks.—This genus is distinguished by the thin exine, triangular shape, and differentiation of the proximal hemisphere.

Discernisporites irregularis sp. nov. (Pl. III, figs. 5, 6, Text-fig. 1)

Holotype.—Slide F 745, ref. 244639, from the *Gastrioceras subcrenatum* marine shales.

Diagnosis.—Size 50 to 100 μ, holotype 80 μ, rays of tetrad mark one-half to two-thirds radius of spore body, tecta flexuous; proximal polar region with short, irregular linear ridges.

Description.—Colour pale yellow, equatorial outline triangular, apices bluntly angled to rounded, side slightly convex. Exine approximately 1 μ thick. Rays of tetrad mark one-half to two-thirds radius, tecta flexuous, lips elevated, folded. Folds parallel to the rays often extend to the equator. The region of the contact area (?) is ornamented by low warts and smooth elongate ridges which coalesce in places Ridges 2 to 3 μ high, 2 to 4 μ wide, and up to 12 μ long. The periphery of the inner, ornamented area is sometimes marked by a $\pm$ definite line (curvaturae ?).

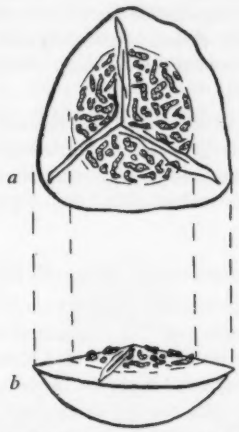
Comparison.—The development of the smooth coalescing ridges in the proximal polar region characterizes this species.

Discernisporites concentricus sp. nov. (Pl. III, fig. 7)

Holotype.—Slide F 732, ref. 090619, from the *Gastrioceras subcrenatum* marine shales.

Diagnosis.—Size 50 to 75 μ, holotype 59 μ, trilete rays two-thirds to three-quarters radius of spore, proximal polar area thickened, infragranular.

Description.—Colour pale yellow to light brown, polar area darker. Equatorial outline triangular with slightly rounded apices. Rays of the tetrad mark two-thirds to three-quarters radius, tecta often flexuous, lips raised. A triangular polar area (? contact area) of the proximal surface is thickened and shows strong infra structure, i.e. infra-



TEXT-FIG. 1*a* + *b*.—*Discernisporites* nov. gen. (*a*) Diagrammatic proximal view. (*b*) Diagrammatic elevation of spore.

granulation. The peripheral boundary of the polar area is $\pm$ distinct and runs concentric to the extrema lineamenta. The thickened area is approximately two-thirds of the radius of the spore. The outer region of the proximal surface is thin, laevigate to faintly infrapunctate, as is the remainder of the exine.

Comparison.—The spores of this species are distinguished by the thickened proximal polar region.

Remarks.—Hoffmeister, Staplin, and Malloy, 1955, figure a spore (pl. 37, fig. 9) and designated by them as Spore Type A which resembles this species. In their description (p. 397) of this single specimen they regarded the thickening as being on the distal hemisphere; but for this fact the spore would be included in the species *Discernisporites concentricus*.

Genus *Punctatisporites* (Ibrahim, 1933) Potonié and Kremp, 1954

(Type species *Punctatisporites punctatus* Ibrahim, 1933)

Punctatisporites densoarcuatus sp. nov. (Pl. II, fig. 7)

Holotype.—Slide F 7SD, ref. 072466, from the " non-marine " roof shales of the Six Inch Mine coal.

Diagnosis.—Size 80 to 140 μ (mean 117 μ—twenty-five specimens measured), holotype 110 μ. Rays of tetrad mark one-half to two-thirds radius (length in holotype 28 μ), exine laevigate to infrapunctate, broad secondary folds.

Description.—Colour light to dark brown, equatorial outline circular to oval. Tetrad rays one-half to two-thirds radius, tecta $\pm$ straight, lips thin, suture usually closed. Exine laevigate, though an indistinct infrapunctation may sometimes be seen. Frequently a long, broad arcuate fold is present.

Comparison.—*Punctatisporites obesus* (Loose) Potonié and Kremp, 1955, is probably a closely related form; however, in *P. densoarcuatus* the rays are somewhat longer, the fissure is mostly closed, and the exine shows a tendency to fold rather than burst along the dehiscence mark.

Punctatisporites cf. obesus (Pl. III, fig. 1)

A group of spores of the size range 95 to 135 μ has been observed to possess for the greater part the characteristic features of *Punctatisporites obesus* as described by Potonié and Kremp, 1955, p. 43. Here however, the rays of the tetrad mark are rarely open and are frequently accompanied by small folds running along their length. If the opening of the fissure with compression is to be regarded as of major significance, this group would deserve a separate specific grouping.

Horst (1956, pl. 21, fig. 31) figures a spore very similar to those seen here, but again the fissure is seen to be open.

Genus *Leiotriletes* (Naumova) Potonié and Kremp, 1954
(Type species *Leiotriletes sphaerotriangulus* (Loose) Potonié and Kremp, 1954)

Leiotriletes concavus (Kosanke, 1950) Potonié and Kremp, 1955
(Pl. I, fig. 6)

Remarks.—Very rare examples have been observed in the " non-marine " and marine shale assemblages.

Kosanke described this species from the Lower McLeonsboro Group—approximately equivalent to Upper Westphalian D. in Europe.

Suite APICULATI

Genus *Mooreisporites* (type species *M. fustis*) gen. nov.

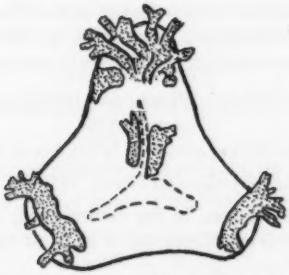
Trilete iso- or microspores, equatorial outline triangular. The apices bear baculae or blunted cone-like projections. The bases of these elements are often fused into a thickened bar or pad which may lie at the equator or be displaced slightly on to one of the polar hemispheres, more frequently the distal hemisphere. Where the thickening is seen at the equator it may simulate apical thickening. Baculae or cones are commonly dispersed irregularly over both proximal and distal surfaces of the spore.

Comparison.—Compared with the genus *Triquitrites* Wilson and Coe, 1940, the apices are not thickened into valvae, but possess projecting elements which may be fused at their bases.

Remarks.—When discussing *Triquitrites inusitatus* Kosanke, Potonié and Kremp (1954, p. 154) excluded this form from the genus *Triquitrites* on the basis of the atypical development of the apices.

Mooreisporites fustis sp. nov. (Pl. I, figs. 1, 2, Text-fig. 2)

Holotype.—Slide F 746, ref. 648134, from the *Gastrioceras subcrenatum* marine shales.



TEXT-FIG. 2.—*Mooreisporites* nov. gen. Diagrammatic distal view of spore.

Diagnosis.—Size 60 to 90 μ, holotype 88 by 76 μ, tetrad rays up to one-half radius of spore body, apices ornamented with well-developed, thick baculae, similar elements may be dispersed on remainder of spore body.

Description.—Colour pale yellow to light brown, equatorial outline triangular with straight to concave sides, apices bluntly rounded. Rays of tetrad mark about one-half radius, tecta slightly flexuous, suture often open. Spore coat approximately 2 μ thick, faintly infrapunctate, sometimes folded. The spores bear at the apices heavy branching baculae, up to 16 μ long and 5 to 9 μ wide. The bases of the baculae

are often swollen and in many cases fused, giving rise to a bar or pad of thickening which lies at or within the extrema lineamenta. Scattered baculae are found dispersed on both proximal and distal surfaces of the spore.

Comparison.—In *Mooreisporites* (*Triquitrites*) *inusitatus* (Kosanke) the baculae are simpler and less heavily developed processes.

Mooreisporites sp.

Occurring with *Mooreisporites fustis* are spores which are within the size range 40 to 55 μ and typically develop simple sub-cylindrical baculae at the apices. In some cases one or two of the apices are devoid of projecting elements.

Since relatively few of these forms have been observed, no diagnosis has been given, but an example is figured (Pl. I, fig. 3) and it is considered that such forms would constitute a different specific grouping to *M. fustis*.

Mooreisporites (*Triquitrites*) *inusitatus* (Kosanke, 1950)

Kosanke in 1950 described this species from the No. 2 Coal Bed of the Carbondale Group of Illinois and included it in the genus *Triquitrites*. Kosanke was in some doubt as to the nature of "The thickening (?) opposite the rays". This factor probably led Potonié and Kremp to reject the form from the genus *Triquitrites*.

On the basis of Kosanke's description (p. 39) and figure (pl. 8, fig. 7) it is proposed to transfer this species to the genus *Mooreisporites*.

Genus *Raistrickia* (Schopf, Wilson, and Bentall, 1944) Potonié and Kremp, 1954

(Type species *Raistrickia grovensis* Schopf in S.W. and B., 1944)

Raistrickia microhorrida Horst, 1956 (Pl. I, fig. 5)

Remarks.—Specimens seen in the marine shale assemblage. Horst recorded this species from Namurian A coals of Mährisch-Ostrau.

Suite MURONATI

Genus *Dictyotriletes* (Naumova, 1937) Potonié and Kremp, 1954

(Type species *Dictyotriletes bireticulatus* Potonié and Kremp, 1954)

Dictyotriletes varioreticulatus sp. nov. (Pl. II, fig. 1*a*, *b*.)

Holotype.—Slide F 7SI, ref. 056550, from the "non-marine" roof shales of the Six Inch Mine coal.

Diagnosis.—Size 70 to 110 μ, holotype 106 μ, outline circular to oval, with approximately twenty-five small conical projections at the extrema lineamenta, reticulum slightly irregular, muri low, rays of tetrad mark two-thirds to three-quarters radius.

Description.—Colour brownish-yellow, equatorial outline circular to oval. Tetrad rays two-thirds to three-quarters radius, tecta sharp and

straight, lips narrow. Exine frequently with secondary folds. Lumen of the reticulum are shallow depressions, up to 15 μ in diameter; muri are low, 2 to 4 μ wide, and give rise to low conical projections at the outline.

Comparison.—*D. maculatus* (Loose) Potonié and Kremp, 1955, resembles *D. varioreticulatus* but is somewhat smaller and the muri appear to be stronger; it also appears much higher horizons.

Genus *Camptotriletes* Naumova, 1937

(Type species *Camptotriletes corrugatus* (Ibrahim) Potonié and Kremp, 1954)

Camptotriletes? juglandilis Horst, 1956 (Pl. II, figs. 2*a*, *b*)

Remarks.—A common species in both coal and " non-marine " shale assemblages. Horst describes this form from Namurian A coals of West Upper Silesia and Mährisch-Ostrau.

Genus *Knoxisporites* Potonié and Kremp, 1954

(Type species *Knoxisporites hageni* Potonié and Kremp, 1954)

Knoxisporites triradiatus Hoffmeister, Staplin, and Malloy, 1955 (Pl. III, fig. 2)

Remarks.—Occasional specimens in the marine shale. H., S., and M., 1955, recorded this species from the Hardinsburg Formation, approximately equivalent to the base of the Namurian in Europe.

Division **Triletes**

Subdivision ZONOTRILETES

Suite ZONATI

Genus *Cirratriradites* Wilson and Coe, 1940

(Type species *Cirratriradites saturni* (Ibrahim) S., W., and B., 1944)

Cirratriradites granulatipunctatus Hoffmeister, Staplin, and Malloy, 1955 (Pl. II, fig. 4)

Remarks.—Rare specimens from the " non-marine " shale assemblage. H., S., and M., 1955, described this species from the Hardinsburg Formation, Chester Series.

Order **POLLENITES**

Division **Saccites**

Subdivision MONOSACCITES

Genus *Endosporites* Wilson and Coe, 1940

(Type species *Endosporites ornatus* Wilson and Coe, 1940) (Pl. III, fig. 4)

Remarks.—This species is the most common form of Endosporites

seen in these assemblages. Occurrence in England recorded (Potonié and Kremp, 1956*a*, after H. V. Smith) from Westphalian A and B.

Endosporites minutus Hoffmeister, Staplin, and Malloy, 1955
(Pl. II, fig. 5)

Remarks.—Specimens seen from coal and "non-marine" shale assemblages. H., S., and M., 1955, described the species from the Hardinsburg Formation.

Genus *Schulzospora* Kosanke, 1950

(Type species *Schulzospora rara* Kosanke, 1950)
(Pl. II, fig. 3)

Remarks.—Spores of this species are common in the "non-marine" shale. The observed maximum size range here is 80 to 101 μ. Kosanke recorded the occurrence in the Battery Rock coal of Illinois, which is about Westphalian A in age.

Genus *Florinites* S., W., and B., 1944

(Type species *Florinites antiquus* Schopf., 1944)
Florinites similis Kosanke, 1950 (Pl. I, fig. 7)

Remarks.—This species occurs frequently in all three assemblages examined here. Kosanke records *F. similis* from the Tivoli Coal bed, Peoria County; approximately Upper Westphalian D in age.

Subdivision POLYSACCITES

Genus *Alatisporites* Ibrahim, 1933

(Type species *Alatisporites pustulatus* Ibrahim, 1933)
Alatisporites nudus sp. nov. (Pl. III, fig. 9)

Holotype.—Slide F 741, ref. 143457, from *Gastrioceras subcrenatum* marine shales.

Diagnosis.—Overall size: range 40 to 60 μ, holotype 55 μ, tetrad rays to margin of laevigate central body, bladders transparent, laevigate.

Description.—Trisaccate spore, central body rounded triangular, laevigate. Colour pale yellow to light brown, exine 1 μ thick. Bladders transparent, laevigate and project 8 to 10 μ from the equator of the central body. Where the bladders lie against the spore body they are frequently folded.

Comparison.—Spores of this species are easily recognized on account of their small size and the complete lack of sculpture or structure on both the central body and bladders.

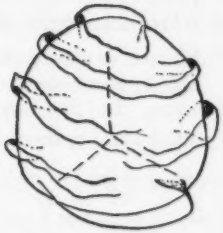
Division ? Saccites

Genus *Proprisporites* (type species *P. rugosus*) gen. nov. (Text-fig. 3)

Trilete iso-, or microspores, equatorial outline of the spore body is

rounded triangular. The spore body is covered by a thin, laevigate perisporal membrane which is strongly wrinkled to form long folds and free lobes, mainly on the distal surface of the spore. The folded membrane runs over the equator as tight folds and on to the proximal surface, leaving the area in the vicinity of the tetrad mark free from folds. Where the tightly folded membrane crosses the equator it is compressed into series of blunt and rounded boss-like projections which give to the outline of the spore a dentate appearance. In places where the membrane runs in the same plane as the equator, it appears as a projecting transparent wing.

Comparison.—The lobate and linear folding of the perisporal membrane is characteristic of spores of this genus.



TEXT-FIG. 3.—*Proprisporites* nov. gen. Diagrammatic distal view of spore.

Remarks.—Other species belonging to this genus have been observed at other horizons in the Namurian of North Staffordshire.

Proprisporites rugosus sp. nov. (Pl. I, fig. 4)

Holotype.—Slide F 747, ref. 150545, from *Gastrioceras subcrenatum* marine shales.

Diagnosis.—Size 65 to 85 μ, holotype 70 by 65 μ, rays of tetrad mark two-thirds radius of spore body, perisporal membrane laevigate, strongly folded, spore body strongly punctate.

Description.—Colour pale yellow to light brown, equatorial outline is rounded triangular. Tetrad rays two-thirds radius of spore body, tecta straight, lips thin but well defined. The strong punctation of the spore body is clearly visible through the laevigate perisporal membrane. The latter projects up to 6 to 8 μ at the equator and is strongly folded. The folds which are long and irregular in outline, run over the distal surface and on to the proximal surface, giving rise to tightly compressed boss-like projections at the equatorial margin.

Comparison.—Spores of this species are distinguished by the strong punctation of the spore body.

Order SPORONITES

Genus *Reticulatasporites* (Ibrahim, 1933) Potonié and Kremp, 1954

(Type species *Reticulatasporites facetus* Ibrahim, 1933)

Reticulatasporites sp. (Pl. III, fig. 3)

Remarks.—A variable group of ? spores which show an irregular network of flattened or rounded ridges, but no tetrad mark has been observed. Size approximately 60 to 70 μ; however, insufficient numbers prohibit the creation of a new species.

Bodies of this type have been seen mainly from the marine shale horizon.

Genus *Indeterminate*

Spore Type A (? Hystrichosphere) (Pl. III, fig. 8)

Description.—Spore (?) circular to sub-circular, colour light brown. No tetrad mark seen. Size approximately 35 μ. Surface densely covered by long tapering spines, 15 to 20 μ long, 4 to 5 μ wide at base.

Remarks.—Specimen present in the marine shale.

Spore Type B (Pl. III, fig. 10)

Description.—Overall size 58 μ, flange 3 to 8 μ wide encircles the equator. Tetrad rays extend to equatorial flange. The latter is thin with a lobate outline. Spore body is triangular with concentrically arranged ridges and lobate thickenings of the exine. The lobes appear in places to overlap on to the flange. Exine infrapunctate.

Remarks.—Specimen seen from the marine shale.

Spore Type C (Pl. II, fig. 6)

Description.—Size 63 by 61 μ. Equatorial flange 4 to 5 μ wide, tetrad rays 24 to 25 μ. The lips of the tetrad rays are thickened to form a tri-radiate area of thickening, 14 to 20 μ wide, which encloses the rays.

Remarks.—Specimen seen from the marine shales.

Microspore Assemblages

This detailed study of the microspore assemblages from a coal seam, marine and " non-marine " shale, which together constitute a relatively thin sequence, has revealed significant differences in both types of spores present and their relative numerical proportions.

For comparison, the relative abundance of each genus in the three assemblages are listed in Table 1 as percentages. The three right-hand columns show the number of species of each genus occurring at each

horizon. The generic frequencies shown in the left-hand columns are also plotted as a histogram (Text-fig. 4).

In all cases the spore counts are based on 750 specimens; however, in the case of the coal and " non-marine " shale counts the first 250 specimens observed were used to determine the proportion of *Lycospora* to other genera. The subsequent 500 specimens were

TABLE 1.—LISTS OF GENERIC PERCENTAGES AND SPECIES TOTALS

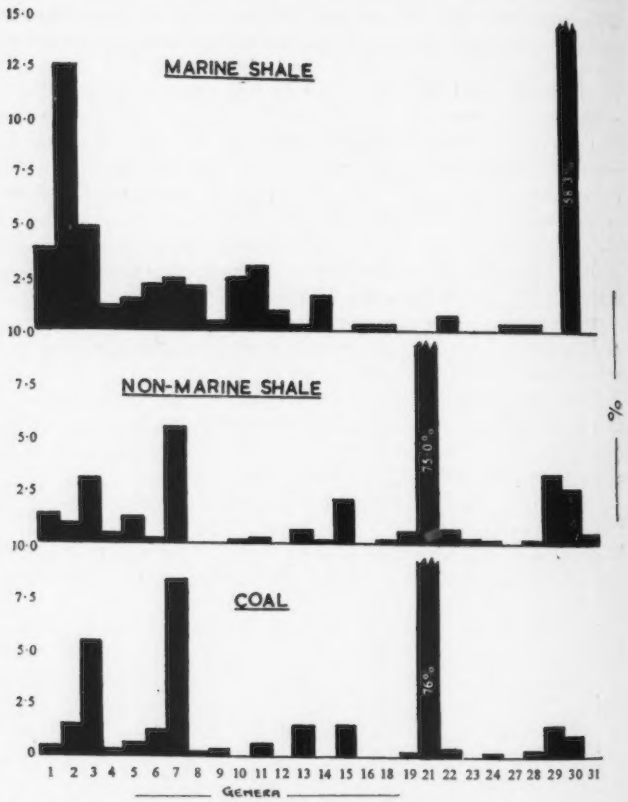
	Genera	Percentage of genera in assemblage			Number of species observed		
		Coal	" Non-marine "	Marine	Coal	" Non-marine "	Marine
1	*Leiotriletes*	0·2	1·3	3·8	1	4	3
2	*Punctatisporites*	1·4	0·8	12·4	3	1	3
3	*Calamospora*	5·3	3·0	4·8	2	4	4
4	*Granulatisporites*	0·2	0·4	1·2	2	2	5
5	*Cyclogranisporites*	0·5	1·2	1·4	1	3	2
6	*Planisporites*	1·2	0·2	2·2	2	1	1
7	*Apiculatisporites*	8·3	5·4	2·4	5	5	9
8	*Lophotriletes*	0·1	S	2·0	1	1	2
9	*Acanthotriletes*	0·2	S	0·4	1	1	3
10	*Raistrickia*	S	0·1	2·4	1	1	3
11	*Verrucosisporites*	0·5	0·2	3·0	2	1	2
12	*Convolutispora*	S	S	1·0	1	1	2
13	*Campotriletes*	1·3	0·7	0·3	1	1	3
14	*Microreticulatisp.*	S	0·1	1·7	1	1	2
15	*Dictyotriletes*	1·3	2·0	S	2	1	2
16	*Reticulatisporites*	NS	NS	0·2	0	0	2
17	*Knoxisporites*	S	S	S	1	1	1
18	*Triquitrites*	S	0·1	0·2	1	2	1
19	*Ahrensisporites*	0·1	0·6	S	1	1	1
20	*Simozonotriletes*	NS	NS	S	0	0	1
21	*Lycospora*	76·0	75·0	S	3	3	1
22	*Anulatisporites* / *Densosporites*	0·3	0·6	0·7	1 / 1	1 / 2	1 / 1
23	*Cirratriradites*	S	0·2	NS	1	1	0
24	*Laevigatosporites*	0·1	0·1	NS	1	2	0
25	*Latosporites*	S	NS	NS	1	0	0
26	*Punctatosporites*	NS	0·1	NS	0	1	0
27	*Alatisporites*	NS	NS	0·3	0	0	2
28	*Endosporites*	0·2	0·1	0·3	1	2	2
29	*Schulzospora*	1·4	3·3	NS	1	1	0
30	*Florinites*	1·0	2·6	58·3	3	3	5
31	*Schopfipollenites*	S	0·4	NS	1	1	0
32	*Mooreisporites*	NS	NS	S	0	0	1
33	*Discernisporites*	NS	S	S	0	1	2
34	*Proprisporites*	NS	NS	S	0	0	1
35	Spore Type A	NS	NS	S	0	0	1
36	Spore Type B	NS	NS	S	0	0	1
37	Spore Type C	NS	NS	S	0	0	1
	Incertae Sedis.	0·4	1·5	1·0			

S = Frequency less than 0·1 per cent. NS = Not observed.

considered disregarding *Lycospora* in order to find the relative abundance of the remaining genera more accurately.

From the distribution of genera through the sediments it is clear in the first instance that the coal and " non-marine " shale are closely comparable in the predominance of *Lycospora*, *Apiculatisporites* and, *Calamospora* in their assemblages; the dominance of the latter two genera is not so marked in the shale, whilst *Schulzospora*, *Florinites*, and *Dictyotriletes* correspondingly increase in numbers. The assemblage

from the marine shale is very different from the others in the occurrence of genera. The reduction in numbers of *Apiculatisporites* continues and *Lycospora* becomes extremely rare; *Florinites* now assumes the



TEXT-FIG. 4.—Histogram of generic frequencies. Numbers below histogram refer to genera numbered in Table 1.

dominant role, constituting 58·3 per cent of the total assemblage. This predominance of *Florinites* is not restricted to this horizon, for in spore assemblages from marine shales at various horizons in the Millstone Grit and lower Coal Measures, *Florinites* has been observed by the author to be the dominant constituent. On the other hand, *Schulzospora* does not maintain the increase in numbers it showed in

the " non-marine " shale and is rare at the marine horizon. *Punctatisporites* is present in its greatest proportion in the marine shale; *Schopfipollenites* reaches a maximum in the " non-marine " shale, but forms less than 0·1 per cent of the coal assemblage and appears to be absent from the marine shale macerations. The *Densosporites-Anulatisporites* group is not common in any of the sediments examined but shows a slight increase in the marine shale assemblage. *Raistrickia* is rare in the coal and " non-marine " separations but is a fairly common constituent (2·4 per cent) of the marine shale assemblage. The new genera *Discernisporites*, *Mooreisporites*, and *Proprisporites* occur as " Accessory Spores " (in the sense used by Raistrick, 1934) in the marine shale microflora. Only isolated examples of *Discernisporites* have been observed from the " non-marine " shale. Complete species lists have been compiled and these show that the total number of species investigated reaches 108, of which seventy-two are present in the marine shale, fifty in the " non-marine " shale, and forty-three in the coal seam. It is clear that whilst many species are common to all three horizons, additional species are present in the shales and the widest variety is present in the marine shales.

The marked contrasts in totals of species and relative abundance of different genera in the spore assemblages from the three sedimentary types calls for some explanation; at this stage of the work such explanations must, however, be regarded as tentative.

Since the coal seam is *in situ*, as indicated by its associated rootlet bed, it may be expected that the microspore assemblage will be derived from a local, specialized swamp type flora. This seems to be the case, for relatively few genera, namely *Lycospora*, *Apiculatisporites*, and *Calamospora*, form the bulk of the assemblage.

The similarity of the " non-marine " shale and coal seam assemblages is marked by the dominance of the two genera *Lycospora* and *Apiculatisporites*. At the same time increases in several genera, including *Dictyotriletes*, *Florinites*, and *Schulzospora*, and slight decreases in others, i.e. *Apiculatisporites*, *Calamospora*, and *Planisporites*, could be interpreted as a broadening, however slight, of the source of derivation of the " non-marine " shale microflora.

The dominance of *Florinites* in the marine shale is striking, but in addition the other genera are also fairly well represented, which when considered in conjunction with the greater variety of forms at the specific level seems to indicate an even more varied parent flora.

However, the abundance of *Florinites* raises a further problem which cannot be fully explained on the evidence of this work alone. Nevertheless, there are three possible reasons for its abundance: (1) Its large air sac would assist widespread dispersal by wind and possibly rivers; (2) It may have had greater resistance to chemical

and vegetable decay; (3) A locally concentrated parent flora marginal to the area of deposition.

Potonié and Kremp (1955, p. 22), in a discussion of the ecology of Carboniferous plant spores, thought some structural features found in mega- and microspores assisted their dispersal. For instance, the large air sac, which is a diagnostic character of the genus *Florinites*, would obviously be of assistance, particularly with regard to wind dispersal, and may account for the abundance of this genus in the marine shale. However, spores of the *Endosporites* type show very little increase in the marine shale (0·3 per cent compared to 0·2 per cent in the coal). This would indicate that the possession of a large air sac may not be the only factor, or even the most important one in accounting for the distribution of *Florinites*. Furthermore, the relatively large proportion in the marine shale of spores of the *Punctatisporites* type, which are essentially smooth, spherical spores, apparently possessing no real dispersal advantages, would tend to detract from theories depending on structural control of dispersal.

It is also very difficult to assess the importance of degradation of the microspores or the relative resistance of various spore types to the prevalent forms of decay. That microspores are subjected to various types of decay or destructive agencies was observed at an early stage by Reinsch (1884, vol. i, p. 4, when he attributed some destructive elements on spores to " minute plant parasites "). A complete discussion of the forms of attack that have been observed is beyond the scope of the present paper, but is worthy of note that differing spore types frequently show a characteristic pattern of destructive attack. The general preservation of the microspores, however, in all the separations from the three horizons here described, allows the majority of specimens to be identified at the specific level. For example, the few specimens of *Lycospora* seen in the marine shale separations can be recognized as species occurring abundantly in the separations obtained from the two other horizons and there appears to be little difference in their general condition.

The overall appearance of the material, including spores, in slides prepared from the maceration of the two shale types and the coal seam, do, however, exhibit subtle differences in preservation of the organic remains. In preparations of marine shale, the spores have a waxy yellow appearance and the wood tissues are typically very dark brown or black, whilst from the coal seam the spores are golden brown and the wood and cuticle tissues are shades of dark and light brown. Although maceration affects to some extent the intensity of colouration in the organic matter, the quality of preservation remains different. Further work is necessary on the subject of preservation under various environments, but the mode of preservation in these

sediments is sufficiently different to allow marine and non-marine organic remains to be distinguished.

The suggestion that the abundance of *Florinites* in the marine shales is due to the peculiar distribution of the parent flora seems possible. The spores or pollen grains attributed to the genus *Florinites* are believed to be derived from plants with Cordaitalean (Florin, 1936) and Coniferalean (Potonié and Kremp, 1955, p. 22) affinities. Hence, a flora in which these plants abounded, marginal to the marine depositional area, could be envisaged as providing this high concentration of *Florinites* in the marine sediment.

Acknowledgments

The author wishes to express his gratitude to Professor L. R. Moore for his advice and encouragement. Thanks are also extended to Dr. C. Downie and Mr. H. J. Sullivan who have read through the manuscript and offered many useful suggestions; to Mr. G. S. Bryant for his assistance in preparing the plates and to Miss T. McCarthy for her help in producing the manuscript. The work was carried out by the author in the Department of Geology, University of Sheffield, whilst he was in receipt of a Robert Styring Research Grant.

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DEPARTMENT OF GEOLOGY,
SHEFFIELD UNIVERSITY.

EXPLANATION OF PLATES

Magnifications × 500 except where stated.
Specimen numbers refer to the collection of the Geological Dept., Sheffield.

PLATE I

FIG. 1. *Mooreisporites fustis* sp. nov. (holotype).

FIG. 2.—*Mooreisporites fustis* sp. nov. Showing the development of a large single bacula on the distal polar region.

FIG. 3.—*Mooreisporites* sp. × 1,000. Slide F 749, ref. 196541. Size 41 μ. Occurrence: Marine Shale.

FIG. 4.—*Proprisporites rugosus* sp. nov. (holotype).

FIG. 5.—*Raistrickia microhorrida* Horst, 1956. Slide F 74D, ref. 186564. Size 50 μ. Occurrence: Marine Shale.

FIG. 6.—*Leiotriletes concavus* (Kosanke, 1950) Potonie and Kremp, 1955. Slide F 746, ref. 040521. Size 65 μ. Occurrence: Marine Shale.

FIG. 7.—*Florinites similis* Kosanke, 1950. × 400. Slide F 741, ref. 190445. Size 140 μ. Occurrence: Marine Shale.

PLATE II

FIG. 1*a* + *b*.—*Dictyotriletes varioreticulatus* sp. nov. (holotype). (*a*) Focus high, on ornament; (*b*) Focus low, on outline.

FIG. 2*a* + *b*.—*Camptotriletes? juglandilis* Horst, 1956. (*a*) Focus high, on ornament; (*b*) Focus low, on outline. Slide F 7SK, ref. 021534. Size 84 μ. Occurrence: " Non-marine " shale.

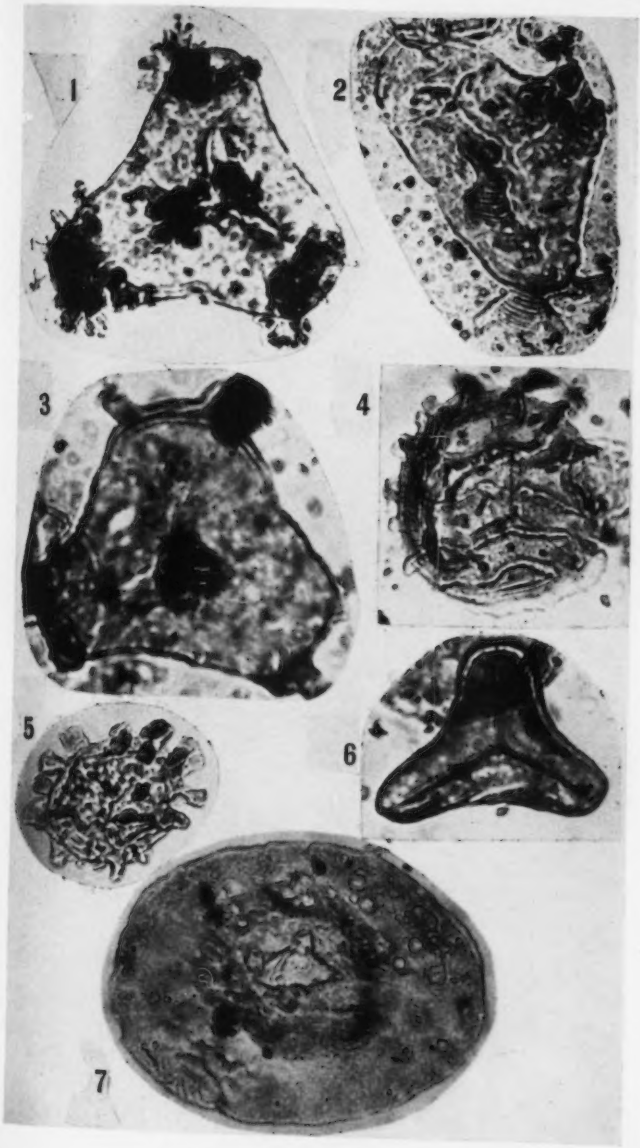
FIG. 3.—*Schulzospora rara* Kosanke, 1950. Slide F 7SI, ref. 148497. Size 98 μ. Occurrence: " Non-marine " shale.

FIG. 4.—*Cirratriradites granulatipunctatus* Hoffmeister, Staplin, and Malloy, 1955. Slide F 7S12, ref. 080638. Size 42·5 μ. Occurrence: " Non-marine " shale.

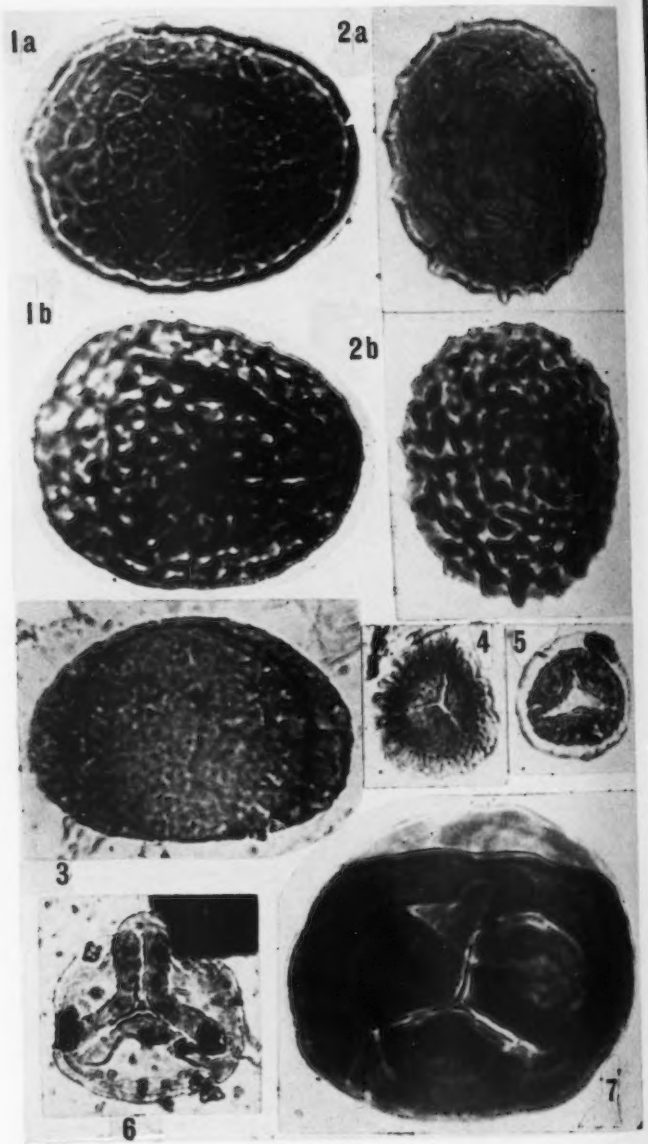
FIG. 5.—*Endosporites minutus* Hoffmeister, Staplin, and Malloy, 1955. Slide F 7SC, ref. 073452. Size 37·5 μ. Occurrence: " Non-marine " shale.

FIG. 6.—Spore Type " C ". Size 63 × 61 μ. Slide F 745, ref. 232579. Occurrence: Marine Shale.

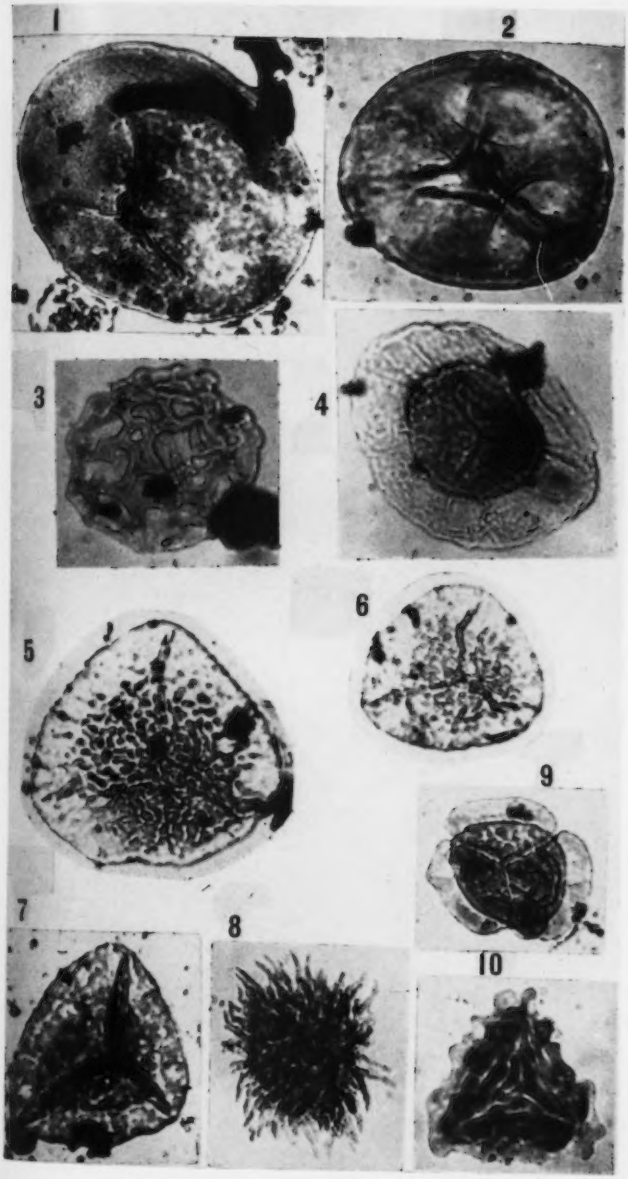
FIG. 7.—*Punctatisporites densoarcuatus* sp. nov. (holotype).



UPPER CARBONIFEROUS PLANT SPORES.



UPPER CARBONIFEROUS PLANT SPORES.



UPPER CARBONIFEROUS PLANT SPORES.

PLATE III

FIG. 1.—*Punctatisporites cf. obesus*. Slide F 745, ref. 088574. Size 106 μ. Occurrence: Marine Shale.

FIG. 2.—*Knoxisporites triradiatus* Hoffmeister, Staplin and Malloy, 1955. Slide F 743, ref. 244609. Size 90 μ. Occurrence: Marine Shale.

FIG. 3.—*Reticulatasporites sp.* Slide F 741, ref. 115490. Size 67 μ. Occurrence: Marine Shale.

FIG. 4.—*Endosporites ornatus* Wilson and Coe, 1940. Slide F 74A, ref. 165572. Size 90 μ. Occurrence: Marine Shale.

FIG. 5.—*Discernisporites irregularis* sp. nov. (holotype).

FIG. 6.—*Discernisporites irregularis* sp. nov.

FIG. 7.—*Discernisporites concentricus* sp. nov. (holotype).

FIG. 8.—Spore Type "A". Slide F 74G, ref. 102510. Overall size 65 μ. Occurrence: Marine Shale.

FIG. 9.—*Alatisporites nudus* sp. nov. (holotype).

FIG. 10.—Spore Type "B". Slide F 74I, ref. 217550. Size 58 μ. Occurrence: Marine Shale.

A Note on the Occurrence of Coal Measures in Eastern County Limerick, Ireland

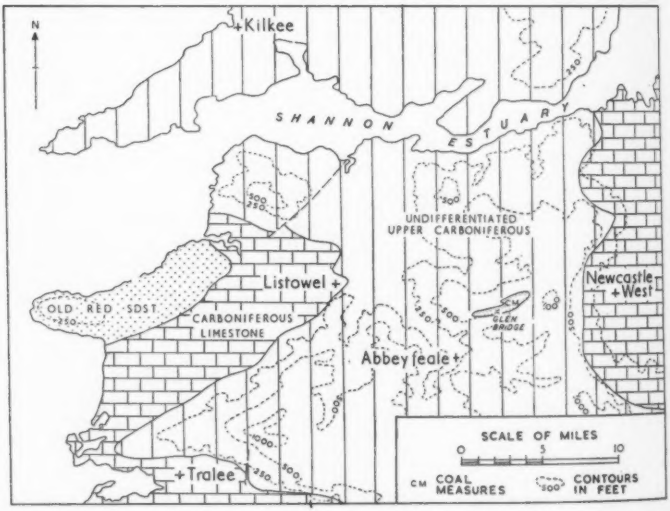
By W. E. Nevill

Abstract

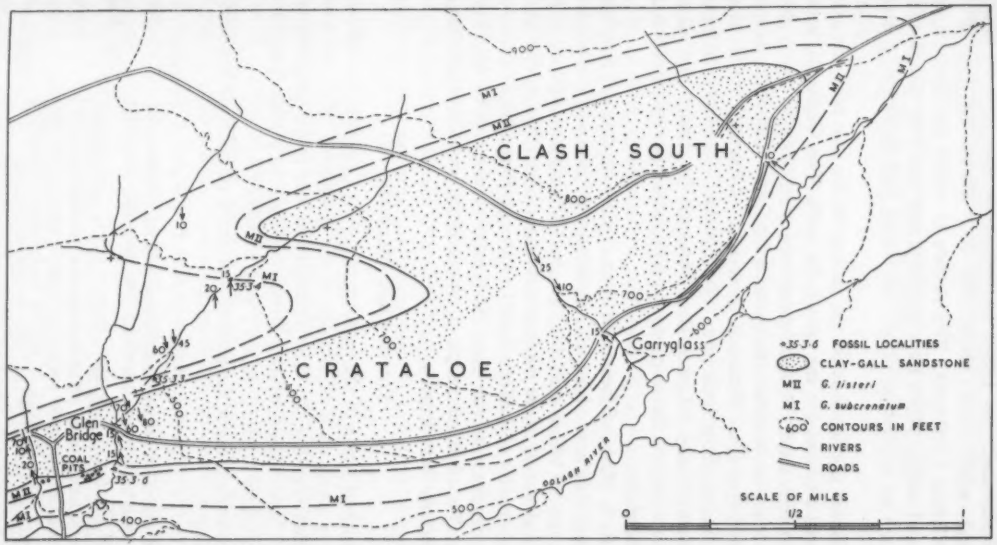
The purpose of this note is to put on record the discovery of Lower Coal Measure strata in the west of Ireland. The succession is approximately 500 feet thick and includes the *Gastrioceras subcrenatum* and the *Gastrioceras listeri* marine bands. Of particular interest is the occurrence of a coarse felspathic sandstone in the cycle of sedimentation which includes the *G. listeri* horizon: the sandstone is very similar in lithology to the distinctive Clay-Gall Sandstone of the Leinster Coalfield.

Introduction

At the request of the Chamber of Commerce of Newcastle West, Co. Limerick, I recently investigated that portion of the Upper Carboniferous outcrop which lies to the west of the town (Text-figs. 1 and 2). The total thickness of the Upper Carboniferous is of the order of 3,000 feet to 4,000 feet, and of this the Coal Measures, which occupy the centre of a broad basinal fold, total approximately 500 feet.



Text-fig. 1.—Location Map, giving the revised interpretation of the area covered by the present work.



TEXT-FIG. 2.—Geological map of the Coal Measure outlier at Glen Bridge.

Topographically the Upper Carboniferous beds form an elevated moorland which rises about 500 feet above the level of the Carboniferous Limestone. The surface is varied by alternate wide ridges and valleys which have a general east and west direction, and which are an expression of an Armorican fold structure of similar trend.

No former publications on the geology of the area took account of the faunal evidence for the age of the beds. The Geological Survey one-inch map, sheet 152, and the accompanying memoir, were available for the first time in 1860. In them all the Upper Carboniferous rocks are classified as Coal Measures. A revision of the map in 1881 shows a subdivision of the beds into "Shale Series" (at the base), "Flagstone Series" and "Lower Coal Measures": under that scheme the greater part of the succession is represented as coming within the last subdivision.

Mr. R. J. Nash, of Newcastle West, kindly granted me permission to publish this note. Six-inch manuscript maps constructed in 1938 by Mr. M. O'Meara and Mr. M. A. Cunningham, officers of the Geological Survey, were made available for inspection by Mr. M. V. O'Brien, director of the Survey. Mr. O'Meara offered helpful comments on the problems of the area. The maps were drawn by Mrs. K. M. Davies. To all these people I am indebted and have pleasure in recording my best thanks.

Lower Coal Measures

The highest strata of the area are of Lower Coal Measure age, and occupy a small tract of country in the townlands of Crataloe and Garryglass (Text-fig. 2). The international base to the Coal Measures —the *G. subcrenatum* Marine Band—outcrops in a stream section at three localities (35.3.3 ; 35.3.4 ; and 35.3.6).

In descending order the general succession of the Coal Measures is as follows :—

	Feet.	
Shales and fine grained sandstones : (discontinuous exposure) thickness uncertain, but probably less than 50 feet	50	(Max.)
Sandstone ; pale, felspathic, medium, and coarse grained ; includes layers of pseudo-conglomerate which are composed of clay-galls enclosed in coarse sand. (The title by which this rock is known in Leinster—Clay-Gall Sandstone—will be used also in western Ireland). .	170	
No Exposure ; strata presumably argillaceous ; the base is the horizon of *G. listeri* (information from disused coal workings)	50	
Coal Seam ; anthracite ; thickness unknown . . .	—	
Fireclay ; minimum thickness 2 feet	2	(min.)
Sandstone ; pale, fine grained	5	
Mudstone ; blue	20	

	Feet.
Mudstone overlain by sandy shale with layers of fine grained sandstone	100
Shale; grey	20
Shale; blue-black, very fossiliferous—*G. subcrenatum* C. Schmidt, *G. listeri* (J. Sowerby) group; Lamellibranchia; Gasteropoda	1
Coaly shale	$\frac{1}{6}$

The uppermost beds of the succession are covered by peat, except for a partial exposure along a stream course at Garryglass, where there are two small outcrops of fine-grained sandstone separated by shale. Chief interest in the succession centres around the thick felspathic sandstone which outcrops continuously in several stream sections. Distinctive by reason of its high felspar content, its state of deep weathering, but especially by the occurrence in it of rounded pebbles of shale, this sandstone can be correlated with the well-known Clay-Gall Sandstone of the Leinster Coalfield (Nevill, 1956, p. 9), where also it presents similar lithological characteristics. A seam of anthracite, estimated to lie about 50 feet below the sandstone, was formerly mined in shallow pits at Crataloe. From the spoil heaps of those workings some fragments of *Anthracoceras* sp. were found in thin bedded blue shale; the fossil evidently indicates the presence of the *G. listeri* marine band. There is no outcrop of the coal nor of the strata between it and the Clay-Gall Sandstone, and this fact suggests that those strata are argillaceous and offer little resistance to erosion.

Comparison with the Leinster Coalfield

This record of the Clay-Gall Sandstone of Leinster 100 miles to the west in Co. Limerick, supplies information useful towards a reconstruction of the palaeogeography of Lower Coal Measure times. The evidence from current bedding and cross lamination indicates that in either case the source of the sediment lay to the south or south-west. The increasing magnitude of the non-sequence beneath the sandstone when traced from north to south across the Leinster Coalfield also suggests derivation of the sediment from a southerly source. Layers of pseudoconglomerate, due to penecontemporaneous erosion and related to the non-sequence, occur in Leinster. The presence of clay-galls in Limerick is therefore suggestive of a stratigraphical break in that area also. But the possibility of their production in a local wash-out should be considered until such time as the question is settled by further mapping.

The simplest interpretation that can be offered for the palaeogeography of Southern Ireland at that time of deposition of the Clay-Gall Sandstone is that a land mass, whose shoreline lay to the

south or south-west, supplied the sediment for the construction of an extensive delta, whose seaward margin advanced towards the north. The presence of the non-sequence when taken in conjunction with the relative coarse texture of the sandstone suggests either that the southern landmass had undergone uplift immediately after the deposition of the *G. listeri* marine band, or that there was a change in climate at that time.

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SCHOOL OF GEOLOGY,
TRINITY COLLEGE,
DUBLIN.

The Amphibolite of Doir'a'Chatha (Durcha), Sutherland

By G. H. Francis

(PLATE IV)

Abstract

The amphibolite at Durcha passes from a dark, hornblende-rich rock, through every gradation of delicate striping and banding by quartzo-feldspathic material out into psammitic Moine schist, within a few metres. Irregular cross-cutting bands of quartz and feldspar which seem to "feed" the delicate stripes can be seen and there are intergrown mixtures of the dark and light components which recall appinites. Chemical and other evidence suggests that the dark rock is a concordant tholeiitic dolerite sill, whilst the macroscopic and microscopic evidence from the pale bands suggests that they are metasomatic in origin and connected with the widespread permeative alkali-injection of the Moine Schists. They seem to have been introduced into the sill along closely-spaced foliation planes parallel with those in the adjacent sediments and with the original contacts of the sill.

Introduction

THE banded amphibolite of Doir'a'Chatha or Durcha, near Invercassley, in Sutherland, is a classic rock type and has been mentioned repeatedly in the literature of the Moine Series. The first record of this rock, by H. H. Read, appears in the Summary of Progress for 1921 (*Mem. Geol. Survey*, 1922). In 1926 Read gave a detailed description and a tentative interpretation of the Durcha hornblendic rocks in the Geological Survey Memoir for Sheet No. 102 in which the locality lies. The rocks are exposed for several metres in the bed of the Allt Doir'a'Chatha close to the croft of Durcha (National Grid Reference 29/501024). Read describes them as follows:—

"Among the different types that occur is a coarse dark green or black rock composed almost entirely of hornblende, the acicular crystals of which show a tendency to lie with their vertical axes in one plane. A slightly different type is one where the hornblendic material is banded with narrow stripes of pale quartzo-felspathic material, and by the increase in the number of such bands the rock takes on a markedly striped aspect. The striping is extremely delicate and persistent and runs parallel with the foliation of the neighbouring granulites. Often on the plane surfaces of the stripes throughout both the quartzo-felspathic and hornblendic portions there are large bladed crystals of green actinolite up to 2 inches in length which lie with their vertical axes in the foliation-planes but show no other orientation. A final type is represented by a rock mainly quartzo-felspathic in

character but with very regular and persistent bands of hornblende often less than $\frac{1}{12}$ in. in thickness.

" In slice (21879, 21881, 21882, 21946) [1] the delicately striped rocks are made up of bands of the following characters :—

" (i) Bands of quartz, microcline, and other alkali-felspars, with very rare hornblende crystals and with trains of small epidote grains. The structure is granulitic and the rock appears to differ in no way from the normal granulite of the Moine Series . . . ,

(ii) Bands similar to the above but containing plates of brown biotite and considerable epidote and rather more hornblende ;

(iii) Bands composed of much hornblende in large poikiloblastic grains, quartz, felspars, and epidote ;

(iv) Bands, often very thin, composed almost entirely of hornblende and epidote. Apatite and sphene are common in all these bands.

" In certain of the associated rocks the banding is not so well marked and the rock (21878) consists of a schistose aggregate of quartz, hornblende, alkali-felspars of which microcline is dominant, biotite, sphene, and apatite ; the hornblende forms large poikiloblastic plates. Another slice (21877) shows abundant epidote, chloritized biotite, and large grains of alkali-felspar and quartz, with scarce hornblende. The most hornblendic rocks (21880) are coarse associations of sieved hornblende prisms and biotite plates with quite subordinate large grains of quartz. The massive hornblende-rocks are sometimes altered to tremolite (21939)."

In discussing the origin of these rocks Read (1926) has noted the similarities between the dark hornblende-rich types at Durcha and rocks of similar appearance at the Cassley Falls nearby ; the latter have a transgressive relationship to the surrounding schists. In the first description of the Durcha rocks Read (1923) was inclined to attribute the banding as " due to their heterogeneous intrusion early in the period during which the granulites received their present structure. Somewhat later the original ferro-magnesian minerals of the striped rocks were probably converted into the stress-mineral hornblende and large blades of actinolite formed upon the foliation planes ". In 1926, after microscopical study, he adopted a new hypothesis, that the massive and the striped hornblendic rocks are all sediments, e.g. " . . . the presence of microcline, a mineral unlikely

[1] H.M. Geological Survey thin section numbers.

to be formed by the regional metamorphism of a doleritic rock, and one commonly occurring in the Moine Granulites, has suggested that the pale bands are of sedimentary origin and are simply granulites of the Moine Series. . . . If it be admitted that the pale quartzo-felspathic bands are sedimentary then the hornblendic bands can be either (1) *lit-par-lit* intrusive or (2) also sedimentary. In favour of their sedimentary nature are the following points : They are extremely regular even when exceptionally thin ; they appear never to coalesce or to cut across the granulite ; there is a gradual passage from hornblendic bands to bands with scattered hornblendes, and from these to what has been taken to be Moine granulite ; and they sometimes break up into lines of separated hornblende crystals. . . . The whole set may be due to the regional metamorphism of marly or chloritic sediments ".

Read (1926) has closely identified the hornblendic rocks of the Airde of Shinness on Loch Shin with those of Durcha. At Arscaig and Sallachy on the further shore of that loch, and along the strike from Shinness, are similar massive and striped rocks and they occur nearby in Strath Grudie. Read has also noted striped hornblendic rocks occurring nearby in Srath Càrnaig, and the Evelix Valley near Dornoch, in the Memoir for Sheet 103 (Golspie). These rocks he compares closely with those of Durcha, although in addition to the minerals developed at Durcha clinopyroxene occurs in the Srath Càrnaig and Evelix amphibolites.

In the Central Sutherland Memoir (Sheets 108 and 109) Read (1931) has described similar striped hornblendic rocks outcropping over much greater areas than those of the Durcha and Dornoch amphibolites. These large outcrops he grouped with " Rocks of Lewisian Type ", lithologically similar to certain rock types in the Lewisian of the foreland and to rocks within the supposed Lewisian Inliers of Central Ross-shire. There are here two subdivisions : (*a*) hornblendic rocks with very regular plane striping, apparently the most closely comparable with those of Durcha ; (*b*) hornblende gneisses, with coarser grain-size and a less regular transition, by increasing pale material to quartzo-feldspathic gneisses containing scattered hornblende individuals. It may be noted that in one case a striped rock described under (*a*) has not been regarded as the product of finely laminated interbedding.

" There are . . . certain striped rocks that appear to result from definite injection of pale material into hornblende-schist. In one such rock . . . the country-rock consists of hornblende schist of speckly type. . . . It is traversed by two sets of narrow plane veins, the first composed of granulitic quartz, oligoclase, and potash-felspar, the second of quartz with quite subordinate alkali-felspar."

In this account and in a later paper (1934) Read has made comparisons between the type occurrence at Durcha, the striped rocks in Central Sutherland, the hornblendic portions of the supposed Lewisian Inliers of Central Ross-shire, and hornblendic rocks of the foreland Lewisian. These comparisons contributed to the view that no Lewisian Inliers are likely to occur within the Moine Series and that that Series is pre-Torridonian and possibly Lewisian in age. The Central Ross-shire Inliers are now discredited wherever they have been re-examined (almost in their entirety) and the day can be foreseen when the stratigraphic and tectonic relationship between the complex gneisses with hornblendic rocks in Central Ross-shire and in Central Sutherland will be demonstrated through detailed field studies in the intervening ground. Cheng (1944) has distinguished a considerable belt of finely laminated hornblendic rocks " of Durcha type " at Bettyhill, Sutherland, showing the typical transition from dark amphibolite through intermediate stages to pale quartz-feldspar schist with trains of hornblende crystals. He prefers, like Phemister (1926), to regard the rocks as varying clastic mixtures of sand and basic volcanic detritus, rather than of sand and marly or chloritic materials—in spite of the absence of ashy structures. In a recent survey of " Moine Geology " Read (1956) has again referred to the widespread occurrence of hornblendic rocks " of Durcha type ", now identified with greater certainty in Central Ross-shire. He defers to Cheng's and Phemister's preference for basic igneous material rather than chloritic or marly materials in the dark bands. Moine rocks like those at Durcha have been noted at Glenelg (Read, 1934) and by Wilson (in discussion on Kennedy 1955), on the north coast at Melness and A'Mhoine, and as far to the south-west as Morar.

Hornblendic rocks identified as being " of Durcha type ", therefore, are represented in wide tracts of the Moine Schists and have a noteworthy place in the literature of the Moine Series.

The interpretation of the evidence at the type locality, originally advanced in tentative terms, has never there been strengthened by further observation or data, but it has been extended to cover a great assemblage of Highland rocks. It is the purpose of this study, which is confined to the small amphibolite body at the type locality, to show that another interpretation may better be invoked at Durcha. There may well be further areas of rocks " of Durcha type " more easily referable to the present interpretation than to the original one and if the phrase is used in a generic sense it follows that the rocks at Durcha are not " of Durcha type " (i.e. with finely laminated interbedding of sand and basic volcanic detrus) ; if it is used purely descriptively then we must admit that there is " Durcha and Durcha ".

Read has examined and rejected the possibility of magmatically

differentiated pale and dark rocks intruding together as an alternating, streaked assemblage (1922, 1926). He has also rejected the idea that the dark rock was injected *lit-par-lit* into the pale rock. The converse situation of the pale rock injecting the dark rock, *lit-par-lit*, is not considered in these studies. There remain sedimentary interbedding, which Read favours, and metamorphic differentiation. The latter is a doubtful starter. Conceivably a homogeneous, unstriped amphibolite rich in quartz and feldspar could recrystallize and differentiate in the solid state into pale and dark bands perhaps under predominantly mechanical conditions (Schmidt, 1932 ; Turner, 1948). However, some of the unstriped quartzo-feldspathic amphibolite would be likely to remain undifferentiated, and no such rock occurs at Durcha. Minor metamorphic differentiation tending to " sharpen " the fine striping of the Durcha rock is a possible subsidiary effect no matter how the striping originally formed.

Lit-par-lit injection and interbedding both involve the intermingling of two contrasted rock types to form the intermediate (banded) material. It will, therefore, be profitable to study the dark and the pale material separately. In the dark hornblendic rocks it will be important to test whether the present concept of a basic igneous composition, or the earlier one of marly or chloritic sediment is valid, and if igneous whether ashy or other structures are preserved. The pale quartz-feldspar rocks ought to be referable either to metamorphosed sands or to granite (whether magmatic or metasomatic).

The Hornblende-rich Rocks

A specimen of the hornblende-rich rock (No. 7) [1] corresponds to Read's description quoted above, and is traversed by a small number of the pale bands parallel to the foliation, as shown in the photograph of a polished specimen of the rock (Plate IV, fig. 2). Of the three bands close together the uppermost is composed entirely of quartz, whilst the other two are quartzo-feldspathic and the middle band has a distinct " eye " in it.

A thin section of an area without veining shows the hornblende to account for nearly three-quarters of the mineral content of the rock. For the rest there is intercrystalline plagioclase, much sericitized, and numerous granules both of clinozoisite and of sphene. Quartz is sparsely represented with the feldspar and the remaining accessories are magnetite, apatite, and zircon. A volume mode of the rock appears in Table 3. In this the plagioclase (An_{17}) has been divided into albite and anorthite for comparison with feldspars in the norm. The plagio-

[1] The numbers in parentheses on this and the following pages refer to a set of hornblendic rocks from Durcha now in the British Museum collection. Registration B.M. 1957, 330 ; this rock is, for example, B.M. 1957, 330 (7).

clase is only rarely twinned, the twins being on the albite and pericline laws ; its composition has been taken from extinctions in crystals cut normal to *a*. Much of the plagioclase is turbid with fine alteration products which appear to embay and surround the fresh areas. Treatment of an etched slice with cobaltinitrite solution brings out a yellow stain in the alteration product which is, therefore, sericite (and not sassurite). A small amount of potash feldspar also present takes a stain.

The hornblende crystals are in sieved, prismatic growth, as described by Read. The prisms vary between 2·0 and 0·1 cm. in length and the numerous granular inclusions consists of quartz, plagioclase, clinozoisite, and the accessories. The pleochroism of the hornblende is strong in the following colours : α, dark straw ; β, dark grass-green ; γ, mid blue-green. The β refractive index is 1·676,[1] the optic axial angle 2V(−) is 50 degrees, and the extinction angle $\gamma \wedge c$ on (010) is 17 degrees. The granular clinozoisite, which is colourless, shows zoning between crossed nicols. It has a refractive index of 1·725, which indicates about 7 per cent of the $Ca_2Fe_3Si_3O_{12}OH$ molecule.

Cutting through the amphibolite obliquely to the foliation are a few veins of chlorite which clearly replace hornblende. Their pleochroism is distinct, with α, colourless ; β, γ, mid-leaf green, and the interference colours are in purple and mahogany tints. Cleavage flakes have a small optic axial angle, usually positive but occasionally negative, and a refractive index of 1·624. These data suggest that the chlorite is a ripidolite (Hey, 1954). This identification is supported by an X-ray powder photograph of the mineral which is closer to that of ripidolite than to that of any other chlorite in the British Museum reference set of powder photographs. The chlorite is not included in the volume mode for the veins are irregular and very sparse.

An analysis of this amphibolite by the rapid spectrophotometric method, carried out by Dr. A. A. Moss, is reported in Table 1, D. It may be compared with analyses of the various rocks to which the dark rock of Durcha has been ascribed : chloritic sediment, marl, or basalt. To begin with, it has not been possible to find an analysis of an unmetamorphosed chlorite-rich sediment. Chorite does occur in a certain quantity in shales and in the shale component of unsorted shale-sandstone mixtures (greywackes). Some greywacke assemblages are banded, and interbedded with them are laminae of the pure shale component. If this was the case at Durcha we would have here the analysis of one of the shale laminae. The analysis is, however, too low in alumina to be regarded as a shale and lacks the normal excess

[1] Optical constants in this paper were obtained using sodium light ; refractive indices are subject to an error of ± 0·002.

of potash over soda of shales. The possibility that it is a marl, particularly a ferruginous marl, is closer to the facts, and the analyses of three ferruginous marls are set down for comparison (Table 1, A, B, C). Compared with those of the Durcha rock their total iron and magnesia are substantially lower, and the large excess of potash over soda which they show, and which may be attributed to the shale they contain, is in contrast to the excess of soda over potash in the

TABLE 1.—THE CHEMICAL ANALYSIS OF THE DURCHA AMPHIBOLITE COMPARED WITH THOSE OF MARLS AND THOSE OF THOLEIITIC ERUPTIVE ROCKS

	A	B	C	D	E	F	G	H
SiO_2	46·81	48·12	50·47	49·1	47·38	48·79	51·63	49·38
TiO_2	0·67	0·78	1·45	1·9	3·65	4·17	2·00	2·59
Al_2O_3	14·00	12·80	12·77	11·8	11·51	11·96	11·77	13·23
Fe_2O_3	5·35	1·60	2·44	4·6	5·17	2·51	3·23	4·79
FeO	—	3·25	2·52	9·6	8·49	12·10	10·47	8·68
MnO	—	0·09	—	0·2	—	0·21	0·35	0·16
MgO	4·66	2·55	5·22	6·9	6·87	5·60	5·02	5·42
CaO	10·36	10·77	8·17	9·4	11·43	10·15	9·34	9·07
Na_2O	0·34	0·60	0·73	2·9	2·02	2·40	2·90	4·28
K_2O	3·67	3·60	3·70	1·5	1·76	0·70	0·91	0·36
H_2O^+	3·36	3·25	3·14	2·1	0·97	0·40	1·40	0·23
H_2O^-	1·21	1·70	—	—	—	0·65	0·68	0·58
CO_2	9·65	9·19	9·80	tr	—	0·37	0·11	—
Cl	—	—	—	—	—	tr	—	—
P_2O_5	0·05	0·65	—	0·1	0·52	0·41	0·29	1·25
Cr_2O_3	—	—	—	tr	—	tr	—	—
V_2O_3	—	tr	—	—	—	0·11	—	—
(Co,Ni)O	—	—	—	—	—	tr	0·04	—
FeS_2	—	0·88	—	—	—	—	0·08	—
SO_3	—	0·24	—	—	—	—	—	—
S	0·05	—	—	tr	—	0·06	—	—
BaO	—	0·01	—	—	—	tr	0·03	—
C*	—	0·24	—	—	—	—	—	—
H*	—	0·04	—	—	—	—	—	—
	100·16†	100·36	100·41	100·1	99·77	100·57†	(100·27)‡	100·02

* Present in organic compounds. † After substracting O ≡ S. ‡ Sums to 100·25.

A. Marl-shale, Silurian, Havdhem, Sweden. Anal., G. Larsson (Munthe, 1921).
B. Shale component of the Maysville Formation, Ordovician, Butler Co., Ohio. Anal., D. Schaaf (Stout, 1941).
C. Marly clay, Quaternary, Michigan City, Indiana. Anal., W. A. Noyes (Blatchley, 1904).
D. Amphibolite in Moine Series, Durcha, Invercassley, Sutherland. Anal., A. A. Moss.
E. Gabbro dyke, Quaternary ?, Bras Rouge de Cilaos, Réunion. Anal., Boiteau (Lacroix, 1912).
F. Basalt, Tertiary, Holmatindur, Eskifjord, Iceland. Anal., H. F. Harwood (Holmes, 1918).
G. Tholeiitic dolerite, Tertiary, N.N.W. of S alen, Mull. Anal., E. G. Radley (Bailey *et al.* 1924).
H. Epidiorite in Dalradian, Ben Vrackie, Perthshire. Anal., H. M. Pantin (Pantin, 1956).

Durcha rock. Finally, and perhaps most important, the marls contain large amounts of carbon dioxide, whilst in the Durcha rock it is present only in trace quantity. The Durcha rock is a typical epidote-amphibolite indicative of the facies of the same name (otherwise the garnet zone of Barrow). We know from field and laboratory studies that impure carbonate rocks are not greatly decarbonated in progressive metamorphism by the epidote-amphibolite facies, and this is borne out by the ankerite-phyllite of the Poorman formation in the Precambrian of the Black Hills, South Dakota (Noble and Harder, 1948). In the upper part of the garnet zone this rock is an ankerite-

quartz-biotite-almandine-muscovite phyllite containing a little hornblende. The original composition is that of a ferruginous marl. In view of this evidence it is unlikely that the Durcha rock ever contained carbon dioxide (held in carbonates) in the quantity present in a marl.

The Durcha analysis corresponds exactly to that of a basalt (of tholeiitic type). All the oxide percentages fall within the ranges known

TABLE 2.—TRACE ELEMENT CONTENT OF THE DURCHA AMPHIBOLITE COMPARED WITH THOSE OF THOLEIITIC ERUPTIVE ROCKS

	1.	2.	3.	4.	5.
Ga	20	*	25	20	20
Cr	45	100	40	30	30
V	200	320	300	200	200
Mo	*	—	—	—	—
Sn	*	—	*	*	—
Li	10	10	6	5	10
Ni	100	40	40	30	15
Co	45	35	40	25	30
Sc	*	30	25	*	35
Zr	100	225	150	100	80
Y	15	50	40	*	30
La	*	*	*	*	—
Sr	300	250	400	200	350
Pb	*	—	*	*	*
Ba	220	50	300	40	220
Rb	65	*	10	*	40
Cs	*	—	—	—	—

1. Amphibolite, Durcha, Invercassley, Sutherland. Spect. S. R. Nockolds.

2. Epidiorite, Ben Vrackie, Perthshire. Spect. S. R. Nockolds.

3. Tholeiitic basalt, Port na Spaniagh, Aird townland, Antrim. Spect. D. J. Swaine (Patterson and Swaine, 1955).

4. Tholeiitic basalt, Blosseville Coast, East Greenland. Spect. D. J. Swaine (Patterson and Swaine, 1955).

5. Tholeiitic dolerite, N.N.W. of Salen, Mull. Spect. S. R. Nockolds (Nockolds and Allen, 1956).

* Indicates an element which is present, but below the limits of quantitative determination, stated by Nockolds and Allen (1953) for Nos. 1, 2, and 5, and by Patterson and Swaine (1955) for Nos. 3 and 4.

for basalt. Alumina is low, whilst total iron and ferric iron are somewhat high, but similar values may be found in the literature amongst analysed basaltic rocks of about the same silica content, and three such rocks are here quoted (Table 1, E, F, G). It is noteworthy that rocks with relatively low alumina and high iron are characteristic of the Non-Porphyritic Central Magma-Type (particularly tholeiites of the Brunton Type) of the Island of Mull (Bailey *et al.*, 1924). They belong to the " iron-rich trend of British Tertiary tholeiites " of Nockolds and Allen (1956). One of the latter rocks is quoted (Table 1, G) although strictly speaking it is more differentiated (silica enriched) than the preceding two which, in this constituent,

compare more closely with the Durcha rock. Finally, we may compare the Durcha rock with one of the Dalradian epidiorites of Ben Vrackie in Perthshire (Table 1, H). Pantin (1926) has divided the rocks of this mass into three groups, of which the present analysis represents the third, Group C, a rock type slightly enriched in ferric iron and distinctly tholeiitic in chemistry. Alumina, although rather higher than in the Durcha rock, is still low and there are notable parallels between these two rocks which will be mentioned below. At the contacts of the Ben Vrackie mass are sediments hornfelsed by its intrusion, prior to the regional metamorphism of the area.

The trace element content of the Durcha rock has been determined spectrographically by Dr. S. R. Nockolds and can be compared with those of the Ben Vrackie epidiorite and the Mull tholeiite (Nockolds

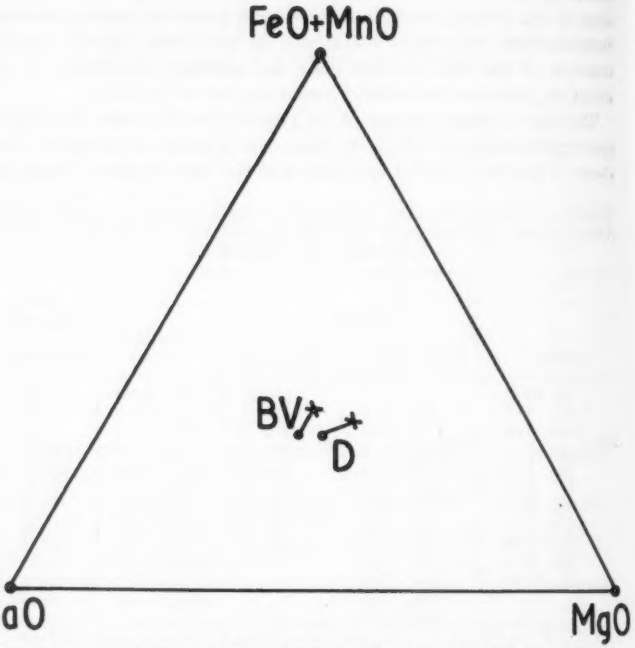
TABLE 3.—THE AMPHIBOLITE OF DURCHA : MODE, NORMS, and HORNBLENDE ANALYSIS (BY CALCULATION), WITH THE HORNBLENDE OF THE BEN VRACKIE EPIDIORITE FOR COMPARISON

DURCHA								BEN VRACKIE
Mode		Katanorm		Mesonorm		hornblende (calc.)		hornblende
Ho	69·2			Ho	70·4	SiO_2	48·4	42·99
Or	1·7	Or	9·5	Or	1·7	Al_2O_3	8·2	12·36
An_{17} Ab	7·9	An_{36} Ab	27·0	An_{16} Ab	7·9	TiO_2	—	1·30
An_{17} An	1·6	An_{36} An	15·2	An_{16} An	1·5	Fe_2O_3	5·1	6·29
Ms	8·9			Ms	8·9	FeO	13·3	14·03
Q	1·9	Di Wo	13·4	Q	1·9	MnO	—	0·25
Tit	4·5	Di En	9·4	Tit	4·2	MgO	9·8	8·08
Clz	2·4	Di Fs	4·0	Clz	2·4	CaO	9·9	10·32
Mt	1·0	Hy En	5·2	Mt	1·0	Na_2O	2·9	2·58
Ap	0·4	Hy Fs	2·4			K_2O	0·3	0·69
Z	0·4	Ol Fo	4·2			H_2O^+	2·1	0·54
		Ol Fa	2·0			H_2O^-	—	0·43
		Mt	4·9					
		Ilm	2·8					99·86

and Allen, 1956) and also with two tholeiitic basalts (Table 2). The Durcha rock is closely comparable with the others, only nickel being somewhat higher (less differentiated) in that rock than in the rest. It is in quite normal concentration for a basalt. No trace element analyses for ferruginous marls have been found for comparison, but they are most unlikely to show better agreement with the Durcha amphibolite than do the tholeiitic rocks.

It is advantageous to recalculate the Durcha analysis to the molecular standard norm of Niggli (recently advocated by Eskola, 1954) for not only can we derive a theoretical basaltic rock in the "Katanorm" (Table 3) but the figures may be recast, using available cations, and

matched to the mode [1] to form a " Mesonorm ". In this the feldspars, muscovite (sericite), quartz, and accessories are formed first [2] and the hornblende, playing its role of " chemical sponge ", takes all the remaining cations (Table 3). This residue may then be recalculated to give an anhydrous analysis of the hornblende and finally, by



TEXT-FIG. 1.—CaO, FeO + MnO, MgO plot (mol per cent) for the amphibolite of Durcha (D) and the epidiorite of Ben Vrackie (BV). Dots represent the rocks, crosses the hornblendes.

assuming 2OH in the formula unit (which ought to be correct to within $\pm$ 1 per cent), the hydrous analysis is derived (Table 3). Allowing for the errors that may have been introduced in the calculations, this hornblende analysis may be compared with that of the hornblende of the Ben Vrackie rock [3] (Table 3).

[1] Recognizing the small discrepancy between volume percentage and molecular percentage.

[2] Clinozoisite can be calculated as if iron-free since it contains only 7 per cent of $Ca_2Fe_3Si_3O_{12}OH$ and amounts to no more than 2·4 per cent in all.

[3] Which may itself be represented by a not impeccable analysis, in that very little combined water is reported.

Apart from the silica-alumina balance in each hornblende there is tolerable agreement, particularly in the notable content of ferric iron in both minerals. We may also note the similarities in optics between these two iron-rich hornblendes, e.g. Durcha $2V(-)$, 50 degrees, $\beta = 1{\cdot}676$, $\gamma \wedge c = 17$ degrees ; Ben Vrackie $2V(-) = 47$ degrees, $\beta = 1{\cdot}680$, $\gamma \wedge c = 18$ degrees. In the CaO − (FeO + MnO) − MgO plot (Text-fig. 1) the tie-lines rock-hornblende are close together and of similar inclination and length (in a diagram in which this vector may vary widely from amphibolite to amphibolite, c.f. Buddington, 1952).

The Durcha chlorite (ripidolite) may be compared with the chlorite in an alkali-injected metadolerite sill (now a chlorite skarn) at Malin Head, Co. Donegal (Holmes and Reynolds, 1947). The analysis of the latter mineral, calculated from that of the skarn, shows it to be just within the group of oxidized chlorites, in the chamosite field, but as oxidation is a feature of alteration it must originally have been a pyknochlorite close to ripidolite in composition (Hey, 1954). The measured refractive index $\gamma = 1{\cdot}627$ of the Malin Head chlorite is higher than that which its chemical composition would suggest.

It seems clear from the chemical and mineralogical evidence considered above that the dark hornblende-rich rock at Durcha is basaltic in origin. The very similar rock at Cassley Falls, for which an igneous origin is not in dispute, may here be quoted as a parallel. The Durcha rock may be a minor intrusion or a lava flow or a deposit of basaltic tuff. No ashy structures can be seen in any of the slides but even so if the rock is a tuff the striping would presumably represent fine interbedding with sandy sediment. This seems unlikely on field evidence as the variation from dark through striped to pale rock takes place within at most a few metres. An horizon of tuff interbedded with sandstone ought to outcrop along strike, if not also across strike, for an appreciable distance yet allowing for poor exposures away from the stream bed, the area occupied by hornblendic rocks at Durcha is of extremely limited extent within a wide tract of psammitic Moine schists. It is, in fact, about the area that would be occupied by an ordinary epidiorite sill. We may now consider the quartzo-feldspathic rocks which make up the pale bands.

The Quartzo-feldspathic Rocks

Read's detailed account of the pale bands at Durcha (1926) requires emphasis in certain points and must be considered together with some undescribed features now to be discussed. Firstly, not all the bands parallel to the foliation are quartzo-feldspathic.[1] There are, as already

[1] " It must be at once admitted that certain of these pale bands are not of normal Moine granulite type " (Read, 1926).

mentioned, some bands with only quartz (Plate IV, figs. 1, 3). Secondly, feldspathic " eyes " can be found in pale bands, even in the most regularly banded rock (Plate IV, figs. 1, 3). Thirdly, there are fine, threadlike cross-cutting veins of later formation carrying muscovite, potash feldspar, quartz, and occasionally a little calcite (Plate IV, figs. 2, 4). These veins appear to have distributed a small amount of the potash minerals and, in a few cases, calcite into the groundmass of the banded rock. In one rock (No. 8) the calcite is concentrated on the crest of a gentle warp or open micro-fold in the planar foliation and is associated there with actinolite needles. These thin veins, which have not been found in the dark amphibolite, may be associated with the fine chlorite veins in that rock. Calcite is not a general groundmass constituent of any of the rocks.

Fourthly, the pale material is not always in delicate and persistent planar striping.[1] It may be scattered in patchy, irregular areas, at first with roughly planar distribution (Plate IV, fig. 2) increasing gradually until it accounts for half the rock or more. Some of these pale areas contain vein-quartz and large feldspars. They run at an angle to the foliation expressed by the hornblendic layers, but can be seen to connect with finer intercalations and bands, parallel to the foliation and indistinguishable from the regular pale stripes in the uniformly striped rock (Plate IV, fig. 4). In other cases the increase of pale material is associated with an apparent recrystallization of the hornblende, which then grows as stout prisms disposed " spillikin-fashion " in the pale ground, whilst the original foliation of the rock can still be made out. This rock is a pseudo-diorite recalling some appinites (Plate IV, fig. 5). The formation of pseudo-diorite from metadolerite by injection is well characterized, and known from a number of areas, e.g. Ellon, Aberdeenshire (Farquhar, 1953), the Malvern Hills, etc.

Fifthly, a study of the microscopic texture of the pale bands brings out features suggesting chemical mobility rather than static (iso-chemical) metamorphism. The sericitization of the plagioclase noted in the dark rock is universal and is well seen in the pale areas of the striped rocks. It has the same habit as in the dark amphibolite of arising in, embaying, and surrounding fresh plagioclase. Cobalt-initrite staining gives a clear picture of the amount and distribution of the potash feldspar which accompanies the sericite. It is found particularly in the areas of strongest sericitization. If the sericite arose by a contribution from potash feldspar we might expect that where there is abundant sericite the potash feldspar would be diminished. This is the reverse of the observed relationship. Potash feldspar, often

[1] " In certain of the associated rocks the banding is not so well marked " (Read, 1926).

with diffuse, shadowy twinning of the microcline grid type, varies markedly in quantity in the Durcha rocks—from the very minor amount in the dark amphibolite (No. 7) and some striped rocks (No. 3) to a very large content in the pale bands of some of the other striped rocks (No. 6). Where abundant sericitization or potash feldspar, or both, are present in the pale stripes biotite takes the place of the hornblende lying within the stripes and at the margins of the adjacent dark rock (pleochroism : α, pale straw ; β, γ, dark olive green). In many cases it can be seen to replace the hornblende and is itself sometimes chloritized. For all these reasons it appears that the pale areas of the Durcha rocks are representatives of an episode of quartz-feldspar metasomatism. In this connection it is noteworthy that quartz-feldspar veining and injection occur in the schists around the amphibolite at Durcha. Although potassic injection has clearly been late-stage, arriving in the pale areas which already contain sodic feldspar the earlier quartz-plagioclase assemblage itself suggests mobility and injection for it occurs in the " feeder " veins oblique to the foliation, and in the " eyes " which accompany the veins. The pale areas are all injections, not injections following earlier sedimentary quartz-feldspar bands.

Read (1926) identified the pale bands at Durcha with the metamorphosed sandy sediments of the surrounding Moine schists because both have granoblastic crystallization of quartz and feldspar and both contain microcline (with, in additon, biotite and accessories found in the psammitic schists). However, granoblastic crystallization is not, by itself, a secure criterion for sedimentary origin, nor is microcline. We have seen that microcline in the pale bands shows many signs of mobility rather than of static (isochemical) metamorphism.

Durcha lies in an area in which the Moine schists have plane foliation visible in closely-spaced *s*-planes which can sometimes be shown by sedimentary structures, e.g. current bedding, at the nearby and analogous area of the Airde of Shinness, to be true bedding planes. These " straight-bedded " Moines with moderate, constant dip of the foliation planes characterize certain areas and are in contrast with intensely puckered and plastically folded foliation planes elsewhere. This is not to say that the plane foliation indicates only minor deformation. They may, in fact, contain drawn-out isoclinal folds, and at Durcha a fine example of boudinage is exposed immediately upstream from the amphibolite. In deformation of this type a concordant, pre-orogenic dolerite sill in the sediments might suffer the same distortions as the surrounding sediments and both might have impressed upon them a similar and parallel set of *s*-planes, guided by the bedding of the sediments and the concordant boundaries of the sill. If such a sill later suffered the sort of permeative injection

we have considered the favoured paths for the incoming fluids would be the fine, closely-spaced *s*-planes, parallel with those in the sediments. Rocks as delicately striped and banded as the Durcha amphibolites could thus result from this kind of *lit-par-lit* injection of a metadolerite sill by quartzo-feldspathic material.

Conclusion

The dark, hornblende-rich rock at Durcha is basaltic in composition and most probably represents a pre-orogenic dolerite sill in Moine psammitic sediments. Metamorphism seems to have impressed a closely-spaced and parallel set of *s*-planes on the schists and on the amphibolite. *Lit-par-lit* injection by quartzo-feldspathic material, present as veins and impregnations in the schist, has followed the *s*-planes into the amphibolite and at its border with the schists has developed the assemblage of delicately and gradationally striped rocks so well known from this locality.

If this alternative explanation for the small occurrence at Durcha is correct then there are at least two possible origins for the rocks of other individual localities labelled " of Durcha type ". They may either be finely interbedded basic volcanic detritus and sand, or they may be *lit-par-lit* injected metadolerite sills or, just possibly, they may represent other phenomena, such as metamorphic differentiation, which have here been considered. It will be of great interest to know which of the explanations may be applied to the great spreads of striped hornblendic rocks in Central Sutherland. Some museum specimens from this tract display extreme fineness and regularity of interbanding and give a much more convincing suggestion of sedimentary interlamination than do the rocks from Durcha itself. On the other hand, the passage from the Central Sutherland Memoir quoted above (p. 27) suggests that injection also plays some part in the production of striped rocks in that area. Each occurrence requires individual examination.

Acknowledgments

I am greatly indebted to Professor H. H. Read who has read through this work and provided valued criticism and comments; also to Dr. W. Campbell Smith for his useful remarks on it. Dr. A. A. Moss kindly carried out the chemical analysis for major elements and Dr. S. R. Nockolds the spectrographic analysis for trace elements. I have also to thank Dr. H. M. Pantin and Dr. S. R. Nockolds for the opportunity to include the unpublished trace element analysis of the Ben Vrackie epidiorite in this paper.

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DEPARTMENT OF MINERALOGY,
BRITISH MUSEUM (NATURAL HISTORY),
LONDON, S.W. 7.

EXPLANATION OF PLATE IV

(Each rock represented at one-half true scale)

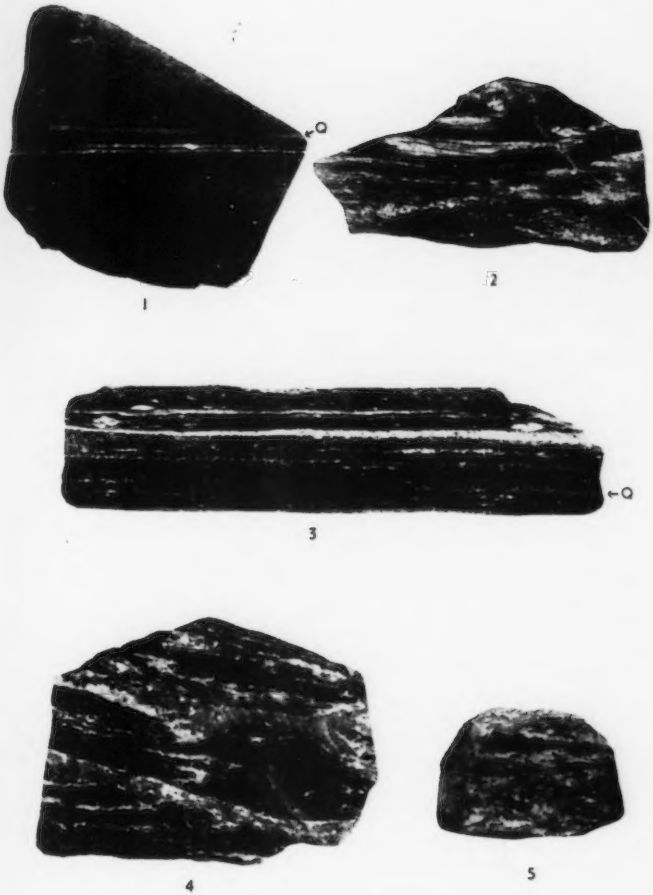
FIG. 1.—Dark amphibolite with sparse plane striping of pale bands in the plane of foliation of the rock. The band marked *Q* is composed of vein quartz, B.M. 1957, 330 (7).

FIG. 2.—Banded amphibolite in which the dark material predominates. The banding is less regular than in the typical rock, and there are fine-grained, late, cross-cutting veins of quartz and feldspar. B.M. 1957, 330 (2).

FIG. 3.—Typical banded amphibolite of Durcha. Note the quartzo-feldspathic eyes in the foliation planes. The band marked *Q* is composed of vein quartz. B.M. 1957, 330 (1).

FIG. 4.—Coarse, pegmatitic quartz and feldspar cross-cutting the foliation of the amphibolite and apparently " feeding " finer quartzo-feldspathic bands parallel to the foliation. The quartz appears grey, the feldspar white. Fine-grained, late, cross-cutting veins of quartz and feldspar traverse the earlier structures. B.M. 1957, 330 (5).

FIG. 5.—Recrystallized amphibolite. The original foliation plane is still marked out by hornblende trains, but much of the amphibole has recrystallized in random, " spillikin-like " growth amongst the abundant quartz and feldspar. The texture recalls that of an appinitic diorite. B.M. 1957, 330 (3).



AMPHIBOLITES AT DURCHA, SUTHERLAND.

Palaeontological Evidence for the Age of the English Wealden

By N. F. Hughes

Abstract

Plant microspores and megaspores are used to correlate the separate occurrences of the English Wealden with the marine Lower Cretaceous of Lincolnshire and with a Netherlands succession. The paper is a preliminary statement on the representation of the Continental stages in the English Wealden.

I. Introduction

THE greater part of the Wealden formation of Southern England which does not happen to contain ostracods, molluscs, or vertebrates, has hitherto been considered to be unfossiliferous. Recent investigation has revealed, however, that plant material of various microscopic sizes occurs commonly at very many levels in most areas. Work in progress on these fossils, when combined with knowledge of the animal fossils and sediments, may well provide a series of zones for North-West Europe.

Three groups of plant material have been considered: cuticule fragments, megaspores, and microspores. The first which range in size from about one centimetre downwards have not yet been used. Megaspores, which average 500 μ in diameter, have been described by Dijkstra (1951), Mädler (1954), and Hughes (1955). Individual specimens of these can be handled and examined under a low-power stereoscopic binocular; although many fossiliferous localities are known, megaspores are not common in the finer grained rocks such as most of the Weald Clay. Microspores, which are mostly between 10 μ and 100 μ in diameter are not normally handled singly; they occur throughout the whole formation although selection of samples is of course necessary to obtain good preparations. About twenty-five species of megaspores and about seventy of microspores are at present known from the Wealden.

Although thin coaly layers occur in the Wealden these are mostly lenticular and consist of compressed trunks or branches. None of the microfossils come from such material but they are found chiefly in siltstones, fine sandstones, shales, and clays. Calcareous rocks yield only damaged spores if any at all.

The plant macrofossils which were described fully by Seward (1894–5, 1913), are with very few exceptions confined to the Fairlight Clay at the very base of the Wealden; the "Jurassic affinities" of these fossils have since been frequently quoted as representative of the whole Wealden flora, but this is misleading.

II. Source of Material and Acknowledgments

The Isle of Wight and Weald outcrop samples are from the author's collection. Kingsclere No. 1 Borehole (d'Arcy Exploration Co.) samples are from the same set as was made available to Dijkstra (1951). The very useful specimens from the Geological Survey borehole at Warlingham, Surrey (Holmes, 1957, p. 32) were kindly provided by Dr. F. W. Anderson, and I am indebted to the Director of the Geological Survey for permission to refer to this important material. Most of the Lincolnshire specimens are either from the Alford borehole through the kindness of Professor H. H. Swinnerton or from outcrop samples generously offered by Mr. R. Thurrell. The samples mentioned are only a small percentage of those studied or available for study ; a more complete account is being prepared for a further publication.

The Netherlands information is from the papers of Dijkstra (1951) and Sung (1955), and I am indebted to the Bataafsche Petroleum Maatschappij of The Hague for being good enough to confirm that Bore B of Dijkstra is Hazerswoude in the South-West Netherlands.

A general review of Jurassic and Lower Cretaceous microspores was recently completed in Cambridge by R. A. Couper of the New Zealand Geological Survey (Couper, 1958). This careful systematic work provided important support for the present study.

III. The Base of the Wealden Formation

The microflora of the Purbeck Beds is generally similar to that of the Lower Wealden. The apparent sharp difference of the Purbeck flora from that of the Kimeridgian and lower beds may be less clear when more samples from the Portlandian and Upper Kimeridgian are studied.

Several easily distinguishable spores such as 17 *Cicatricosisporites dorogensis*, 41 *Pilosisporites trichopalillosus*, etc. (see fuller lists in Table, p. 44, and legend) enter in the Middle Purbeck and continue through most of the Wealden. They are joined by 37 *Concavisporites punctatus*, 87 *Parvisaccites radiatus*, etc., at the base of the exposed Fairlight Clay, and these are sufficient to separate the Wealden from the Purbeck. The lack of outcrop in Sussex and the absence of a satisfactory section in Dorset have precluded further consideration of this point for the present ; material from borings in Sussex is likely to provide an answer, but there is in any case ostracod information from these horizons (Anderson, 1939 and 1940). Correlation with the Purbeckian/Berriasian stage boundary as discussed by Bartenstein and Burri (1955) involves floral work not yet attempted, in France.

IV. Location of the Stage Boundaries

(*a*) *Berriasian/Valanginian*

In the north (England, Netherlands, Germany) this is as yet more accurately presented as a distinction between Infra-Valanginian and Valanginian.

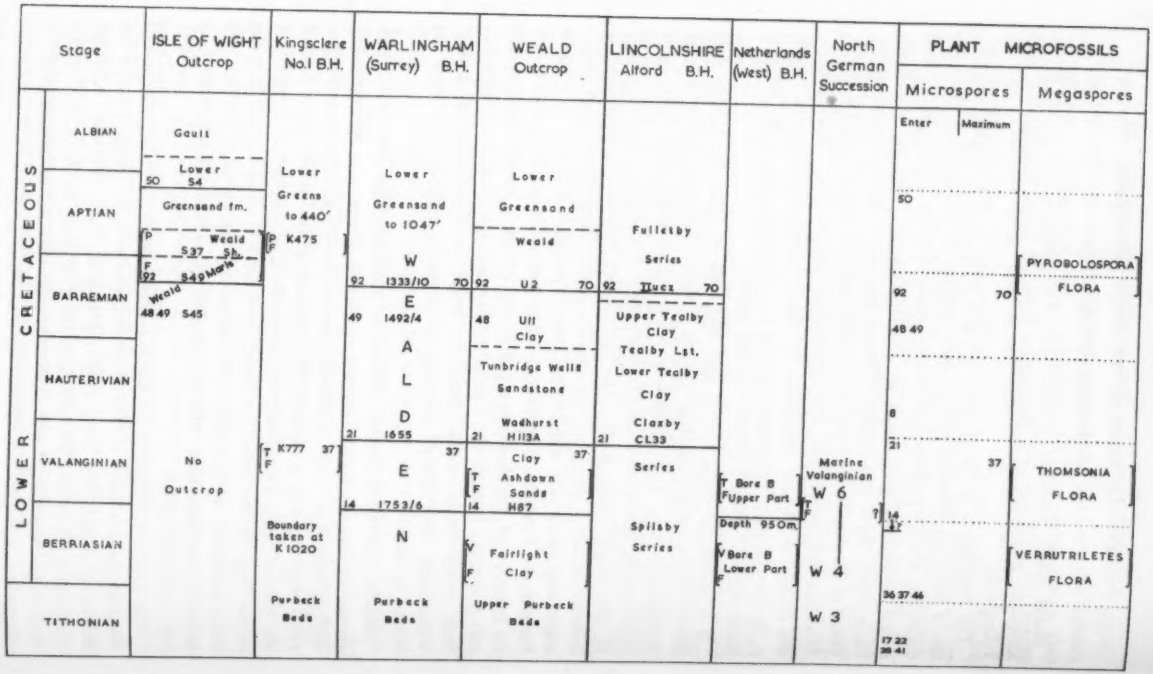
The megaspore flora of the Fairlight Clay of the coastal section east of Hastings contains two or more species of *Verrutriletes*, the very distinctive *Pyrobolospora pyriformis*, *Horstisporites reticuliferus*, and several laevigate forms such as *Trileites spurius*. In the Ashdown Sands above there is a totally different megaspore flora dominated by species of *Thomsonia* such as *Th. pseudotenella*, *Th. midas*, and *Th. divisa*, *Minerisporites marginatus*, *Dijkstraisporites decorus*, etc. This remarkable change is closely paralleled by that recorded in Dijkstra (1951, p. 19) for the then unlocated Bore B (= Hazerswoude, S.W. Netherlands) at the " critical depth " of 950 metres.

It is stated by Sung (1955) that the beds of Bore B—Upper Part (above 950 m.) which he described as " paralic littorals " are of Lower Valanginian age. It is obviously tempting to regard the beds lying conformably below as probably Berriasian and hence the position of my line 14 on Table, p. 44 ; the Bataafsche Petroleum Maatschappij, however (*in litt.*, 1957), advise caution about these lower beds which might well be of any age from Lower Valanginian down to Middle Purbeck (= German Wealden 1). The possibilities are narrowed by the presence of *Pyrobolospora pyriformis* which is known in England only above the base of the Fairlight Clay and not from the Purbecks ; these lower beds could therefore only be Berriasian or Lower Valanginian, the latter meaning a slight raising of the line 14 (Table, p. 44).

Mädler (1954) describes *Thomsonia pseudotenella* and other new *Thomsonia* species from German localities which are unfortunately only published as code numbers, but he kindly informs me (*in litt.*, 1957) that there is a definite *Thomsonia*-horizon in Wealden 4/5 of the Thören area. *Th. pseudotenella* enters as an important constituent of the flora of the Ashdown Sands and Bore B—upper part, but the other members of this flora, *Th. midas*, *Th. divisa*, etc., are not yet known from Germany. The tendency of this argument is to move my line 14 down slightly.

The German Wealden divisions 4–6 are taken by Allen (1955) and Bartenstein and Burri (1955) to fill the whole of the upper part of the Berriasian stage, but Sung (1955) places at least Wealden 6 in the Valanginian (Lower). The arrangement entered on Table, p. 44, is therefore by no means final, but it incorporates new palynological facts for discussion.

The line 14 mentioned above is named from the microspore 14


Stage
ISLE OF WIGHT Outcrop
Kingsclere No.1 B.H.
WARLINGHAM (Surrey) B.H.
WEALD Outcrop
LINCOLNSHIRE Alford B.H.
Netherlands (West) B.H.
North German Succession
PLANT MICROFOSSILS
Microspores
Megaspores
Enter
Maximum
LOWER CRETACEOUS
ALBIAN
APTIAN
BARREMIAN
HAUTERIVIAN
VALANGINIAN
BERRIASIAN
TITHONIAN
Gault
Lower Greensand fm.
Weald
Wealden Marls
No Outcrop
Boundary taken at K1020
Purbeck Beds
Lower Greens to 440'
K475
K777
Lower Greensand to 1047'
W
E
A
L
D
N
E
1492/4
1655
1753/6
Lower Greensand
Weald
U2
Ull Clay
Tunbridge Wells Sandstone
Wadhurst Hill3A
Clay
Ashdown Sands
H87
Fairlight Clay
Upper Purbeck Beds
Fullerby Series
Tlucx
Upper Tealby Clay
Tealby Lst.
Lower Tealby Clay
Claxby
CL33
Spilsby Series
Bore B Upper Part
Depth 950m.
Bore B Lower Part
Marine Valanginian
W 6
W 4
W 3
PYROBOLOSPORA FLORA
THOMSONIA FLORA
VERRUTRILETES FLORA

Appendicisporites tricornitatus which enters in England at H87 in the very top of Fairlight Clay e in the coast section (see White, 1928), and appears to mark approximately the same horizon as the megaspore change; it enters at Warlingham at a depth of 1,753½ feet, which is well above the provisional base for the Wealden. No microspore work has been published on the Dutch or German rocks. It should be emphasized that in detail the Fairlight Clay has so far only been considered as it stands in the coast section.

(*b*) *Valanginian/Hauterivian*

The entry of the large microspore 21 *Cicatricosisporites brevilaesuratus* is recorded at the depth of 1,655 feet at Warlingham, at locality H113A in the Upper Wadhurst Clay on the coast and from low in the Tunbridge Wells Sands near Horsham. This spore happens to be one of the few "associated" spores (with the leaf genus *Schizaeopsis americana* of the Potomac series); the macrofossil has not been recorded in England but this lack might be expected because almost all of Seward's Wealden flora was from the Fairlight Clay.

The same spore enters the Lincolnshire succession at locality CL33 in the Hundleby Clay which is above the base of the Claxby Ironstone series. This has been taken on marine fossil evidence to be just below or just above the stage boundary Valanginian/Hauterivian; the plant microfossil line 21 is thus believed to approximate to the boundary, with the possibility that it may prove to be a little lower—in the Upper Valanginian.

This spore correlation is reinforced by a maximum development of 37 *Concavisporites punctatus* just below Warlingham 1,655 feet,

LEGEND TO TABLE

Microspores: (Numbers refer to author's standard record sheets).
Illustrations of most species will be found in Couper (1958) and the two new species will shortly be described elsewhere by the present author.
8. Microfoveolate trilete spore (MS. n.sp.).
14. Appendicisporites tricornitatus Weyland and Greifeld 1952.
17. Cicatricosisporites dorogensis Pot. and Gelletich 1933.
21. ,, brevilaesuratus Couper 1958. MS.
22. Klukisporites pseudoreticulatus Couper 1958. MS.
35. Trilobosporites bernissartensis Del. and Sprumont 1955.
36. ,, apiverrucatus Couper 1958. MS.
37. Concavisporites punctatus Delcourt and Sprumont 1955.
41. Pilosisporites trichopapillosus (Thiergart) Del. and Spr. 1955.
46. Cingulatisporites valdensis Couper 1958. MS.
48. ,, complexus Couper 1958. MS.
49. ,, sp. (MS. n.sp.).
50. ,, foveolatus Couper 1958. MS.
70. Classopollis torosus (Reissinger) Couper 1958.
92. Clavatipollenites sp. Couper 1958. MS.

Megaspores: All Wealden megaspores are illustrated in Dijkstra (1951) or Potonié (1956).
Correlation: Full lines represent palaeontological correlations. Lithological boundaries appear as broken lines only if considered here (or for clarity). Numbers representing author's localities and borehole depths appear in the middle of each column, palaeontological information being on either side. Formation thicknesses are not to scale.
Adjustment: Arrow beneath the figure 14 in the Microspore column shows the direction of adjustment if this proves necessary.

low in the Tunbridge Wells sands near Horsham and in Kingsclere boring at 777 feet; the maximum is even observed in a subdued form in CL8, a locality a little below CL33 (Lincolnshire). Higher up the spore 8 *Foveotrilites* n.sp. enters at CL9 in the Upper Claxby Ironstone and at 1,573 feet at Warlingham; this line is definitely in the Lower Hauterivian on marine evidence (Swinnerton, 1937).

(*c*) *Hauterivian/Barremian*

This boundary has not yet been located by plant microfossils, nor is it clearly distinguished in the Lincolnshire marine succession. On general grounds, including the French evidence, Allen (1955) inferred that it should be near the base of the Weald Clay of the Weald. As this in no way conflicts with the other propositions here advanced, the evidence can be left to accumulate. The German Barremian succession near Hildesheim (Lipps, 1923) might be examined palynologically in this connection.

(*d*) *Barremian/Aptian*

The pollen grain 92 *Clavatipollenites* sp. enters the succession at S49 middle to high in the Isle of Wight Wealden Marls of Compton Bay, at U2 of Windfallwood Common which is low in Weald Clay III (uppermost division of Reeves, 1948), at 475 feet in the Kingsclere borehole (but samples are lacking for some distance below this) and at 1,333 feet in the Warlingham borehole. In Lincolnshire this pollen grain enters at locality II ucz (of Swinnerton) in the Alford borehole; this lies between 150 and 159 feet depth and is just above the base of the Lower Roach of the Fulletby series. Although this is likely to be below the Barremian/Aptian stage boundary it will at least act as a reference to which the latter may subsequently be tied. The Lower Roach has few fossils and the stage boundary may prove to be higher than the level suggested (see Table, p. 44); the 92 line would then lie in the Middle Barremian.

There are two direct lines of supporting evidence for this pollen correlation. One is a maximum of 70 *Classopollis torosus* which occurs in the Lincolnshire, Weald Clay, and Warlingham samples mentioned, and the second is the presence of the *Pyrobolospra* megaspore flora with *P. vectis* and *P. hexapartita* in Kingsclere, Isle of Wight, and also Dorset samples. Both are marked on the Table.

V. The Top of the Wealden Formation

In the Isle of Wight the Weald shales and just possibly the top of the Wealden Marls are Lower Aptian in age. The Perna Bed is a satis-

factory position in a continuous succession (at Atherfield) to divide Wealden from Lower Greensand formations but the stage boundary may be as low as the Hypsilophodon Bed (see White, 1921). This does not conflict with the evidence presented by Allen (1955, pp. 274–5) although he unfortunately refers to a Wealden/Aptian junction which is a confusion of terms. The Wealden is a rock unit (formation) and if the term is used for a facies this should be clearly stated; it should not be used as a time-unit (see Arkell, 1956).

In the Weald the upper part of Weald Clay III at least, must be within the lower part of the Aptian stage (see Table). At Warlingham the provisional base of the Atherfield Clay at 1,047 feet is nearly 300 feet above the 92 microfloral line here suggested.

VI. Other Horizons

(*a*) Upper Aptian. Plant microfossils have been collected in the Isle of Wight (and Dorset) from rocks presumed to be well up through the Aptian into the Albian stage. The microflora differs conspicuously from that of the Wealden as might be expected, and a prominent line is marked by the entry of 50 *Cingulatisporites foveolatus* at S4 in the top of the Ferruginous Sands, Blackgang Chine, Isle of Wight (also in Dorset). This spore occurs at Warlingham at 815 feet in the Folkestone Beds succession but will probably appear lower on further sampling. The Weald outcrop has not yet been studied.

(*b*) Base of exposed succession, Isle of Wight. The lowest available sample S45 from near Brook Point (Wealden Marls) yields a flora very similar to S49 but lacking 92 *Clavatipollenites*. It also contains the species 48 *Cingulatisporites complexus* which enters at U11 in Weald Clay II at Henfield Brickworks, and 49 *Cingulatisporites* sp. which enters at Warlingham at 1,492 feet. For these reasons the exposed Wealden of the Isle of Wight is believed to be all Barremian or later in age. The Arreton borehole was unfortunately not cored in this part; some flush samples kindly supplied by the British Petroleum Co., Ltd., have not yet provided satisfactory information on lower Wealden in the Isle of Wight.

(*c*) Belgian Wealden. Delcourt and Sprumont (1955) do not give any precise data on localities and horizons which are presumably various. One spore described however, *Aequitriradites inconspicuus*, occurs in England only in the Upper Barremain/Lower Aptian part of the Warlingham borehole succession. The macrofloral and other microfloral indications suggest horizons corresponding to the English Wealden and there is no sign of microfloras as late as the Albian (Allen, 1955, p. 276); the scattered deposits probably vary greatly in date but it may now be possible to assist in correlating them.

VII. General Conclusions

(*a*) Without palaeontological evidence, a scheme of subdivision of the Wealden can only be erected on general grounds ; it is therefore fortunate that such a scheme as was proposed by Allen (1955) does not differ greatly from the present one based on plant microfossil evidence. Allen suggested that the English Wealden " is well suited to be the standard succession for purposes of direct correlation " ; the plant microfossil evidence now presented in outline is considered to give substance to this view in that all the stages appear to be well represented. No further reference is made to the correlations of Wolburg (1950), which were very adequately refuted in 1955 by Allen and Anderson. On Table 1 in the present paper only such horizons as are directly under discussion have been firmly indicated ; others are left to be inserted as the work continues. Although it may be necessary as already suggested to move the correlation lines slightly within the stage framework, the lines themselves are considered valid as they are based on many observations (see Legend of Table, p. 43).

(*b*) Spores and pollen have been found to be widely distributed in all non-marine strata of suitable lithology (see Section I) which have not been altered or weathered. They have also been collected from marine strata of the English Jurassic, Lower Cretaceous, and Tertiary ; their presence in these beds is probably due to transport in river-water as much as by wind dispersal. Admittedly the preservation is often poorer in marine strata and quantities are likely to fall off away from land but within a reasonable distance (perhaps 50–100 miles according to circumstances) of a shore line, sediments of suitable lithology may well yield microspores, etc. This independence of facies is potentially very valuable in correlation problems such as the present one.

(*c*) The few spores here selected as markers by their entrance level form only a small part of the microflora of nearly 100 species whose abundance ratios and locality frequencies (Harris, 1953) have yet to be fully explored. In many cases the plants to which the microfossils belonged are not at all accurately known but this does not prevent the Wealden microflora from being easily distinguishable from that of the beds above and below. It is evident also that a continuous (evolutionary) change is detectable in the Wealden flora and if it proves to be true that the formation represents most of the time occupied by four stages of the Lower Cretaceous, this new abundance of fossils could be of botanical as well as stratigraphical value.

(*d*) Floral correlations of the kind postulated between Lincolnshire and the Weald must be confined to relatively local application because of possible climatic zonation. Such evidence as is available at present suggests that this danger is small in the Lower Cretaceous compared with the Tertiary where it exists but is, however, fairly well understood.

(*e*) Finally, it is realized that there are obvious difficulties in palynological work where the parent plants are not available for study, which may make necessary occasional re-appraisals or alterations. The general picture, however, is of a profusion of fossils, some of which are quite definitely of stratigraphical value.

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SEDGWICK MUSEUM,
CAMBRIDGE.

Further Data on the Petrology of the Saxa Vord Schists of Unst, Shetland Isles

By N. J. Snelling

Abstract

The polymetamorphism and facies classification of the Saxa Vord Schists are discussed on the basis of further chemical and mineralogical data now available.

Introduction

THE geology and petrology of Unst have been thoroughly described by Read (1934, 1937) ; the purpose of this paper is to supplement the data already published on the Saxa Vord chloritoid schists which are the major component of the Saxa Vord Block, one of the main tectonic units of the island. The composition of the chloritoid from these schists has been discussed elsewhere (Snelling, 1957*a*).

Petrography

In hand specimens the chloritoid schists are very fine grained silvery-grey rocks with small bottle green porphyroblasts of chloritoid. On weathered surfaces projecting simple crystals often occur and are clearly pseudomorphs after andalusite. On the surface of some specimens rounded projecting crystals of garnet occur. In thin section these schists are composed of abundant muscovite ($\gamma = \beta = 1{\cdot}600 \pm 0{\cdot}003$) usually showing a high degree of preferred orientation irregularly orientated porphyroblasts of chloritoid, chlorite ($\beta = 1{\cdot}633 \pm 0{\cdot}003$), iron ores, and quartz. The andalusite crystals are composed of a shimmer aggregate of white mica in which there commonly occur randomly orientated prisms of kyanite ; in one specimen a grain of andalusite was observed. Relic grains of staurolite are very common, the mineral is full of quartz inclusions, pleochroic in shades of pale yellow, and usually somewhat chloritized. Chloritoid has not been observed replacing staurolite but laths of chloritoid commonly sprout from relic grains of staurolite. Garnet is rare but when present forms prominent idiomorphic porphyroblasts. In the garnetiferous schists the andalusite pseudomorphs have been completely replaced by white mica and it is very unusual to see garnet and kyanite in the same slide. When they do occur together it is obvious that the rock is banded with kyanite-chloritoid but garnet free layers and garnet-chloritoid but kyanite free layers. A garnet, separated from a muscovite-chlorite-schist has been analysed (Table 1, No. 9) and is an almandine-rich species. The heavy mineral suite from which the analysed garnet was purified also contained small amounts of chloritoid

and staurolite, indicating that the chlorite-schist had been derived from a chloritoid schist. It was not possible to separate enough garnet for analysis from a chloritoid-schist unaffected by the dislocation metamorphism ; however, the refractive indicies of garnets from these schists were the same as that of the analysed garnet and it seems reasonable to assume that their composition would be very similar.

Read (1934) interpreted this rather complex mineral assemblage as due to an earlier metamorphic episode resulting in the production of staurolite, andalusite, biotite, and probably garnet, followed by a second episode which resulted in the formation of kyanite and chloritoid and the destruction of the earlier minerals. He expressed some uncertainty over the behaviour of garnet. In the specimens collected by the writer garnet is seen to include staurolite and chloritoid and in one section it occurs in skeleton form developing from laths and scales of chlorite interspersed among quartz grains. Thus, it seems likely that garnet is a product of the second metamorphic episode together with kyanite and chloritoid.

A third metamorphism, later than that producing chloritoid and kyanite, is developed adjacent to the structural discontinuities which mark the boundaries of the Saxa Vord Block. This metamorphism is characterized by the formation of chlorite and scarce epidote, " the rocks being fine-grained often puckered, schistose, aggregates of quartz, chlorite, muscovite, iron oxide, and epidote " (Read, 1934). Heavy mineral separates from these rocks invariably contain a few grains of chloritoid, staurolite, kyanite, or garnet though these minerals are not usually visible within the limited area of a thin section.

Chemistry

Analyses of the Saxa Vord schists are given in Table 1 and plotted on an A.K.F. diagram in Text-fig. 1. Like many other staurolite and chloritoid schists the Saxa Vord chloritoid schists are rich in alumina, poor in alkalies and lime, and have a high ratio of iron to magnesia. The proportion of soda to potash is rather high, particularly in view of the virtual absence of plagioclase feldspar from these schists, and suggests that the white mica may contain an appreciable amount of the paragonite molecule. When compared with the composition of staurolite and chloritoid schists from the Barrovian metamorphic zones of the south-east Highlands of Scotland (Snelling, 1957*b*) the Saxa Vord chloritoid schists show slight but significant differences. The *alk*, *c*, and *mg* values all tend to be lower, differences which are even more pronounced if the Saxa Vord schists are compared with the typical mica and garnet-mica schists of the Barrovian zones. Assuming that metamorphism has been essentially isochemical these differences

would suggest that the Saxa Vord pelites [1] in their unmetamorphic state were somewhat more mature, i.e. highly differentiated, than the Dalradian pelites of the south-east Scottish Highlands region. Although chemical analyses are few, the petrographic similarities of the pelitic schists of the Shetland region suggest that they share the chemical characters of the Saxa Vord Schists, a factor which must be borne in

TABLE 1.—ANALYSES OF ROCKS AND MINERALS FROM THE SAXA VORD SCHISTS, UNST, SHETLAND ISLANDS

	1.	2.	3.	4.	5.	6.	7.	8.	9.	9a.		
SiO_2 .	54·56	55·63	46·46	53·73	52·76	55·40	58·44	23·48	37·82	Si.	3·019	
TiO_2 .	0·96	1·05	1·30	1·05	1·16	1·27	1·07	2·55	0·58	Al.	2·032	2·062
Al_2O_3	25·20	25·87	29·48	26·07	22·75	20·15	19·04	39·71	21·60	Fe^{+++}	0·030	
Fe_2O_3	4·85	2·46	6·65	2·65	3·02	4·27	7·39	3·79	0·50	Fe^{++}	2·228	
FeO .	4·63	5·19	3·93	6·55	8·36	6·43	2·56	20·73	33·31	Mg.	0·127	2·836
MnO .	0·03	0·07	0·05	0·01	0·04	0·11	0·07	0·66	0·20	Mn.	0·014	
MgO .	1·96	0·91	1·00	1·61	1·49	2·56	2·09	2·00	1·07	Ca.	0·432	
CaO .	0·62	0·46	0·44	1·20	0·94	0·25	0·43	0·31	5·05	Ti.	0·035	
Na_2O .	1·18	2·30	2·24	1·31	1·11	1·33	2·40	n.d.	n.d.			
K_2O .	2·33	2·71	4·07	1·59	4·12	3·23	3·39	n.d.	n.d.			
H_2O^+ .	3·17	3·39	4·24	3·52	2·99	4·20	2·85	6·77	n.d.			
H_2O^- .	0·21	0·02	0·09	0·18	0·83	0·06	0·17	—	n.d.			
P_2O_5 .	0·08	0·04	0·09	0·08	0·01	0·45	0·08	—	n.d.			
	99·78	100·10	100·04	99·55	99·58	99·71	99·98	100·00	100·13			
Sp. Gr.	2·89	n.d.	2·85	2·94	2·67	n.d.	2·75			$N = 1·812 \pm 0·003$		
Niggli Values.												
si. .	191·0	203·2	140·8	183·6	177·6	206·5	217·0					
al. .	51·9	55·8	53·7	52·5	45·3	44·3	41·4					
fm. .	36·8	27·8	28·9	34·0	38·8	42·9	40·3					
c. .	2·3	2·0	1·5	4·3	3·4	1·1	1·6					
alk .	9·0	14·4	14·9	9·2	12·5	12·3	16·7					
mg. .	0·28	0·17	0·16	0·24	0·19	0·24	0·29					
k. .	0·56	0·44	0·55	0·53	0·71	0·62	0·48					

1. Kyanite-chloritoid schist with relics of staurolite, from footpath ¾ mile north-west of Housi Field, Unst.
2. Kyanite-chloritoid schist with relics of staurolite and andalusite, 600 yards north-west of Saxa Vord, Unst.
3. Chloritoid-muscovite schist, Ritten Hamar, 600 yards north-west of Saxa Vord, Unst. (Snelling, 1957*a*).
4. Chloritoid-garnet schist, summit of Saxa Vord, Unst.
5. Chlorite-garnet-muscovite schist, 500 yards south of summit of Saxa Vord, Unst.
6. Chlorite-muscovite schist, locality as for 5.
7. Chlorite-muscovite schist, Cliva Geo, Norwich, Unst.
8. Chloritoid, analysis corrected for inclusions (Snelling, 1957*a*). For analysis of parent rock see No. 3.
9. Garnet from chlorite-garnet-muscovite schist, No. 5.

9a. Garnet analysis No. 9 calculated to give number of metal atoms : 12 oxygen.

All analyses by the writer.

mind when attempting any correlation of sedimentation, structures, and metamorphic history with the Moinean and Dalradian systems of the Scottish mainland.

Comparison of the Saxa Vord chloritoid schists with the chlorite schists produced by the dislocation metamorphism indicates that metasomatic processes were at work during this metamorphic phase. The *al* values are lower suggesting that aluminium silicate has been removed in solution (Turner and Verhoogen, 1951, p. 468), while the *k* values are on the average higher suggesting the addition of potash or removal of soda. Numerous other features of the metamorphic

[1] The term pelite is here used in the broad sense suggested by Joplin (1942).

rocks of Unst were interpreted by Read (1933 and 1934) as indicating the availability of an abundant supply of fluid capable of causing metasomatic changes, particularly during the dislocation metamorphism.

Facies Classification

The association of chloritoid with almandine garnet clearly indicates that the Saxa Vord chloritoid schists belong to the albite-epidote-amphibolite facies. According to the A.K.F. diagram (Turner and Verhoogen, 1951, fig. 64) chloritoid may occur in three assemblages :—

(1) Chloritoid + muscovite + kyanite (the Saxa Vord schists show that this is not a vacant field as indicated by Turner and Verhoogen).

(2) Chloritoid + muscovite.

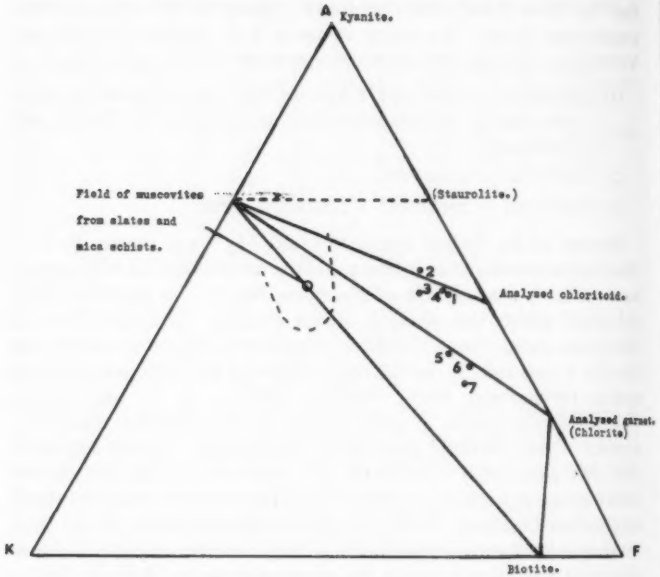
(3) Chloritoid + muscovite + almandine garnet.

Because of the limited degree to which Mg^{++} can replace Fe^{++} in chloritoid and almandine garnet the above assemblages usually contain some other phase capable of absorbing Mg^{++}. In the Saxa Vord chloritoid schists this phase is always chlorite. The association, in chloritoid schists within the almandine-garnet zone, of muscovite and chlorite is also seen in the chloritoid schists of the Stonehaven coastal section (Williamson, 1953 ; Snelling, 1957*b*) ; in this area biotite which normally occurs in pelitic schists of the almandine zone only appears when chloritoid gives place to staurolite. It was suggested that this association of chlorite and muscovite in the Stonehaven chloritoid-garnet schists was due to the failure of the rocks to reach equilibrium (Snelling, 1957*b*), but the similar association of the Saxa Vord chloritoid schists raises the possibility that the antipathy between chloritoid and biotite within the greenschist facies (Browne, 1922 ; Tilley, 1925 ; Read, 1934 ; Harker, 1939 ; Williamson, 1953 ; Seki, 1954 ; and Snelling, 1957*b*) extends into the albite-epidote-amphibolite facies.

When plotted on the A.K.F. diagram the analyses of the Saxa Vord chloritoid schists fall very near the muscovite-chloritoid join. Bearing in mind the inaccuracies inherent in silicate analyses, the possible departure of the composition of muscovite from that of the ideal formula, and the approximations and assumptions made in calculating the A.K.F. values (for instance, all iron has been calculated as FeO and no correction made for magnetite and ilmenite), the observed minerals assemblages are in good agreement with those that would be expected from the plot of the analyses on the A.K.F. diagram.

The muscovite-chlorite schists are clearly the result of metamorphism under the conditions of the greenschist facies. It can be seen from the

A.K.F. diagram that the plots of the three analysed muscovite-chlorite schists fall on the join between muscovite and aluminous chlorite. Garnet when present in these schists is obviously unstable, being replaced by chlorite. Kyanite and chloritoid have not been observed in thin sections of these schists but a few grains of these minerals are usually to be found in the heavy mineral separations leaving little



TEXT-FIG. 1.—Modified A.K.F. diagram showing plots of analysed rocks and minerals from the Saxa Vord schists. Rocks numbered as in Table I. (Albite-epidote-amphibolite facies.)

doubt that the muscovite-chlorite schists were derived from the chloritoid schists. The absence of kyanite and chloritoid does not indicate that they were unstable under the conditions of the dislocation metamorphism, for this metamorphic episode was associated with changes in chemical composition of the chloritoid schists which modified the composition so that it could be expressed as a mixture of chlorite and muscovite only.

Although the first metamorphic episode resulted in the formation of staurolite and andalusite the plots of the chloritoid schists on the A.K.F. diagram fall well below the staurolite-andalusite (kyanite)

field ; furthermore, much of the original andalusite has been replaced by white mica even though the breakdown of staurolite to chloritoid releases alumina. If the Saxa Vord schists of the first metamorphic episode were composed entirely of andalusite, staurolite, and muscovite then it would be impossible to avoid the conclusion that the chloritoid producing metamorphism was associated with considerable alkali metasomatism. If, however, biotite was also a product of the first metamorphic episode then the crystallization of a proportion of the potash as biotite instead of muscovite would make available a certain amount of alumina which could form andalusite. The crystallization of biotite would also absorb iron and magnesia which would otherwise go to form staurolite, so making more alumina available to form andalusite. Any biotite originally present must have become unstable at the onset of the chloritoid producing metamorphic episode, the released potash combining with much of the andalusite to form the shimmer aggregates of white mica, and the iron and magnesia combining with the staurolite to form chloritoid, any magnesia not absorbed in this mineral giving rise to chlorite. Read was of the opinion that biotite was formed during the first metamorphic episode but does not give the evidence on which he bases his conclusion. The writer has found no petrographic evidence to confirm Read's opinion so the cause of the sericitization of the andalusite crystals must remain in doubt.

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ISOTOPE GEOLOGY SECTION,
GEOLOGICAL SURVEY OF CANADA,
OTTAWA.

The Structure of the Grantown Granite Complex, Morayshire

By David H. Mackenzie

Abstract

The field relations and petrography of the Grantown Newer Granite are described. The structure of the country rocks—Moine gneisses—is compared with that of the numerous blocks included in the granite, the results being synoptically presented. The blocks originally bore the same orientation as the country rocks and have been rotated in the granite during its emplacement. From east to west three zones of orientation, showing increasing rotation of blocks from their original position, are recognized in the granite. As the granite lacks an internal penetrative structure the kinematics of the blocks in the granite remains uncertain. All the evidence suggests that the granite did not form in situ, but was emplaced in a plastic state by dilation of the country rocks mainly along their foliation.

Introduction

THE Grantown Granite lies a few miles to the north-west of Grantown-on-Spey in south Morayshire, and is emplaced in pelitic and quartzo-feldspathic gneisses of the Moine Series. The complex extends for 3½ miles from north to south and for 2½ miles from east to west, the relief being about 600 feet. Roughly equidistant from the mass are the large Newer Granite plutons of Cairngorm, Monadhliath, Moy, Ardclach, and Ben Rinnes. Unlike these plutons the Grantown Granite, although a Newer Granite, is medium grained and non-porphyritic and is characterized by a large number of inclusions of country rock ranging in size from a few inches across to 100 yards long.

Hinxman (in Horne, 1923, p. 50) has summarized the salient features of the complex thus :

> " The granite contains many inclusions, large and small, of the surrounding pelitic schists. The larger of these, some of which are more than half a mile in length, preserve the *strike* of the foliated rocks outside the granite mass ; the smaller included fragments are often lying at all angles, having evidently been torn off and carried along with the magma." (My italics.)

Anderson (in Hinxman and Anderson, 1915, p. 39), in describing the southern half of the mass, recorded that the inclusions " sometimes occur more than half a mile from the margin " and that " the country rock is veined with granite up to a mile from the main mass ", thus emphasizing the difficulty of drawing a definite boundary to the body.

The problem presented by the Grantown Granite is to account

satisfactorily for the numbers, the size, and more particularly the orientation of the included blocks, that is, to elucidate as far as possible what Hinxman has called the " nature of the intrusion ". It is necessary to determine the source of the blocks and whether they retain their original positions or have moved in the granite. If they have moved one must look for the geometrical evidence from which it might be inferred how they moved.

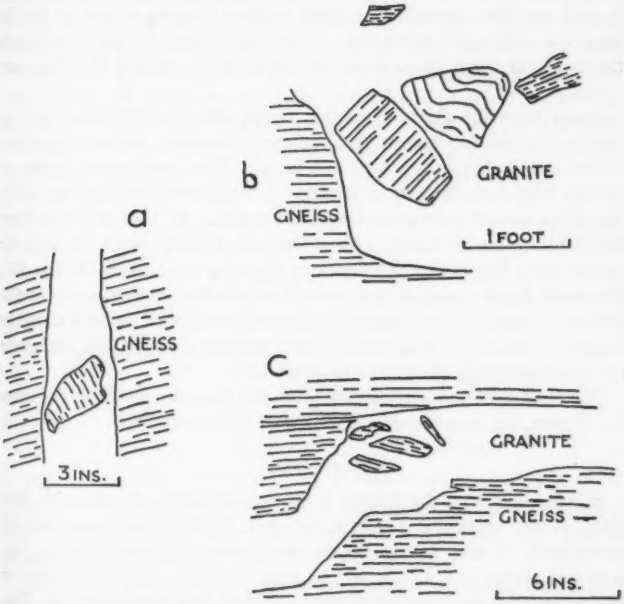
Therefore the investigations directed towards a solution of these problems require a study of the field relations and petrography of the granite, and a comparison of the structure of the country rocks with the structure of the inclusions. An attempt has been made to keep the problem of the mode of emplacement distinct from the more speculative problem of the petrogenesis of the granite.

Field Observations

Contacts of the granite with the country rocks may be either concordant with or transgressive to the prominent foliation of the latter. The contacts do not follow any other planar structure in the country rocks such as axial plane foliation or joint planes. All the contacts are sharp ; contact metamorphic effects are totally lacking. The outer contact of the granite mass is difficult to map because of the large number of granitic and pegmatitic offshoots, both concordant and transgressive, from the main body. The contact is thus a zone in which blocks included by granite pass outwards into highly veined country rock. The outer contact dips concordantly eastwards or south-eastwards on the east and south-east of the mass but is only seen at two localities, Beinn Mhor and Huntly's Cave. A broad tongue of country rock projects into the granite at Beinn Mhor. On the west side of the granite at Creagan na h-Othaisge the contact zone is steep but its exact orientation cannot be determined. The strike of the foliation in the country rocks tends to be parallel to the strike of the granite contact zone. Despite poor exposure of some lengths of the boundary, particularly to the north and north-west, it is clear that the complex has a lensoid outcrop.

Large numbers of inclusions of unaltered country rock, whose surface area constitutes a large fraction of the present surface area of the complex, are found throughout the granite. The representation of a few very large elongate inclusions on the Geological Survey 1-inch maps (Sheets 74 and 84) is schematic only, as on the ground the blocks are found to be much more numerous than indicated and are not greater than 100 yards in lateral extent. The pattern of granite-outcrops within the complex is reticulate, as if formed by interconnecting sills and dykes. As the " sills " are more abundant and wider than the " dykes " the reticules are elongate parallel to the outcrop of the

"sills". Stated conversely, the included blocks are tabular parallel to their foliation and appear to have been totally enclosed by granite. There is no evidence to suggest that the "sills" and "dykes" formed at different times. The largest exposed area of granite is 300 yards (north–south) by 100 yards and lies towards the middle of the complex. In general the blocks are angular, few being rounded. The areas from which individual blocks were detached cannot be ascertained with



TEXT-FIG. 1.—Rotated blocks of gneiss in granite, west side of Creag Liath.

confidence expect for some cases where blocks occur in thin veins (Text-fig. 1*c*).

Several examples have been noted of small blocks of gneiss embedded in granite adjacent to large blocks, and rotated relative to the large blocks (Text-fig. 1). This relationship is found both in veins and in larger granite bodies. Rotation on this scale was also noted by Hinxman (in Horne, 1923, p. 50).

The geometrical relationships between the margins of the granite veins and the structures of the country rocks which they cut indicate that there was dilation normal to the plane of each vein. Reddish

granite veins cut the larger granite sills and are sometimes edged by pegmatite.

In the field the granite is remarkably homogeneous throughout but in some exposures there is a distinct but variable irregularity in the composition ot the rock shown by small planar bodies rich in biotite which are mutually parallel over distances of up to several feet. Their orientation is random over the mass as a whole and with regard to visible contacts. An occasional vague discontinuity in composition is seen as faint irregularly curved patches slightly richer in biotite than the surrounding granite. The significance of the biotite-rich sheets is not clear, there being no evidence to suggest that they are " flow-planes ".

Apart from the above cases the granite has nowhere been seen to have a directed structure of its constituent minerals. At most localities in the granite joints are well developed. They are mainly steep or vertical with a wide range of trends. A small proportion of the joints dip either east or west at intermediate angles. At Tom a'Chaisteil on Beinn Mhor and at Huntly's Cave westerly dipping joints are filled by quartz veins which bear slickensides plunging west-north-west at 50°. The veins mark reversed faults which acted after emplacement of the granite. Therefore the Grantown Granite by virtue of the lack of either foliation, lineation, or a regular joint pattern is unsuitable for study by the Cloos methods of granite tectonics.

The field evidence is consistent with the presumption that the mass is a Newer, i.e. post-tectonic, Granite of Caledonian age.

Petrography

In hand specimen the granite is medium grained, equigranular, and pink or grey in colour ; quartz, feldspar, biotite, and garnet can be recognized. In thin section the texture is seen to be equigranular, the rock only being porphyritic in one rare variant (p. 62). No form- or lattice-orientation of the constituent minerals has been observed. The most common minerals and their percentages are indicated in Table 1 where the average of fourteen modal analyses is given. Each analysis consisted of a count of 1,000 to 1,350 points on specimens from randomly distributed localities in the mass ; individual modes were calculated to the nearest 1 per cent.

The maximum diameter of the quartzo-feldspathic minerals is 3 mm. ; quartz and microcline have the greatest size range. The mica crystals are up to 1·5 mm. in length.

Quartz is anhedral and shows undulose extinction. The crystals of plagioclase (An_{20} to An_{30} throughout the mass) are subhedral, with square, rectangular, or triangular outlines indicating that they are cuboidal in shape. Twinning is on the albite law, and the twin lamellae

are sparse and thin. Zoning of the normal continuous type is common, and up to seven zone boundaries, sub-parallel to the crystal margins, have been observed in a single crystal. The maximum zonal composition range is An_{25} to An_{10} from the core to the thin outermost zone.

Some crystals of oligoclase show evidence of rounding of corners and formation of re-entrant angles and cracks at an early stage of growth. For this reason changes of crystal form with stages of growth cannot be generalized. A few other crystals show, by the abrupt intersection of zone with crystal boundaries, that they were probably derived from a larger crystal. Blebs of quartz sometimes occur in the outer parts of oligoclase crystals. Oligoclase and microcline are commonly intergrown in such a fashion as to suggest that the latter is replacive. A complete gradation is seen from patches of optically continuous microcline in plagioclase to islands of optically continuous

TABLE 1.

	Range of vol. %	Average mode, vol. %
Quartz . .	33–45	38
Oligoclase . .	11–42	24
Microcline . .	5–42	27
Biotite . .	1–16	7·5
Muscovite . .	0–10	2·5
Accessories . .	0–2	1
		100·0

oligoclase in microcline. Oligoclase is commonly altered to secondary mica, particularly in the late reddish veins cutting the granite. Zoisitization is, however, rare.

Microcline forms anhedral crystals twinned on the albite and pericline laws, and in about half the specimens on the Carlsbad law also. Microcline-microperthite is common, containing narrow stringers of albite. Biotite is red-brown or dark brown in colour while muscovite is less common than biotite; both occur as tabular crystals. The accessory minerals seldom exceed 0·5 mm. across and comprise garnet, epidote-clinozoisite, magnetite, pyrite, apatite, zircon, and sphene.

At different localities in the mass there have been observed two variants which grade into the normal granite over a distance of a few feet, while the area covered by each variant is a matter of a few square yards. The first, from a locality on the south-west side of Gorton Hill, is composed almost entirely of equigranular microcline crystals which are rimmed by narrow zones of small microcline granules. Occasional large crystals of pyrite occur (up to 10 mm. across) and

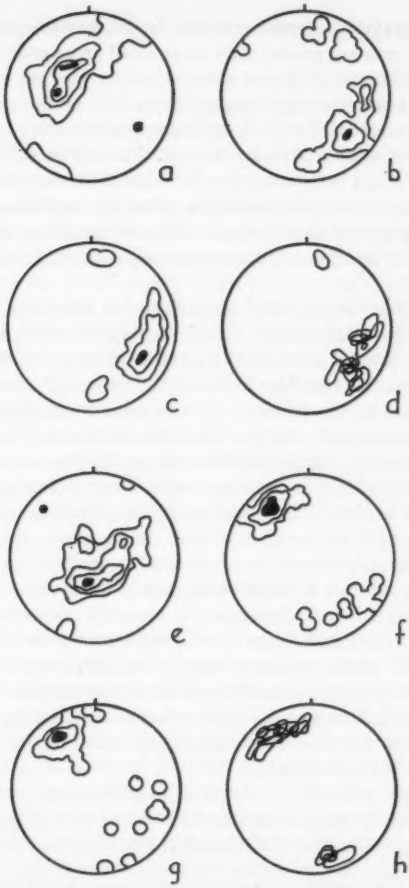
accessory epidote and sphene are well developed. Quartz and oligoclase increase in abundance towards the normal granite and the accessory minerals become smaller and sparser. The second variant, observed on the west side of Creag Liath, appears porphyritic, the sporadic "phenocrysts" being aggregates of microcline crystals which are almost optically continuous with each other and have granular margins indicating breakdown.

The petrographic evidence suggests that there has been breakdown of some of the feldspar since its crystallization and resorption of some of the oligoclase during its formation, followed by slight potash metasomatism Little can be inferred of the history of the other minerals. The association of oligoclase in apparent equilibrium with epidote suggests that the granite belongs to the upper epidote-amphibolite facies.

Petrographically the country rocks are typical gneisses and schists of the Moine Series ; the mineral assemblages in intercalated pelitic, basic, and calc-silicate rocks indicate the lower amphibolite facies. The blocks within the granite are indistinguishable, in hand specimen or in thin section, from the country rocks. The blocks are pelitic, semi-pelitic, and psammitic in composition but pelitic types predominate and appear to represent the continuation within the granite of tracts of pelitic rocks to north, east, and south of the mass. From the petrographic features of the blocks it is not possible to say whether they have risen or sunk with respect to the wall-rocks.

The Structure of the Country Rocks

The main features of the structure of Mid-Strathspey are illustrated by Text-fig. 2*a–d*. The prominent foliation and banding of the rocks has a general dip to the south-east while the π-poles tend to lie in a girdle about an axis which plunges south-east at about 30° (Text-fig. 2*a*). The spread of the maximum contour represents the dip to the east, south-east, or south-south-east depending on locality. No indication of the large-scale fold style is given by this diagram. Axial plane foliation is developed in some micaceous layers and usually dips gently east or north-east. Plots of the attitude of small folds and lineations from the whole area are shown in Text-figs. 2*b* and 2*c*. Both diagrams have a strong maximum at a plunge of about 30° to the south-east. The lineations, being parallel to an axis of flexural folding are *B*-lineations. Both lineations and small folds spread into a girdle which lies in the plane of the regional foliation. This spread is the result of a regional swing in the trend of the fold axis and does not mean that the full range of spread is found at any one locality, a fact which is readily appreciated by sub-division of the area into districts (see Mackenzie, 1957). The small concentration of axial structures



TEXT-FIG. 2.—A comparison of the structure of the country rocks of Mid-Strathspey (*a–d*) with that of the inclusions in the Grantown Granite (*e–h*). Lower hemisphere equal area projections.

(*a*) Poles of 785 foliation surfaces ; full circle, axis of girdle ; contours, 1–3–5–7 per cent per 1 per cent area.

(*b*) Axes of 160 small folds ; contours, 1–5–15 per cent.

(*c*) Axes of 157 lineations ; contours, 1–5–15 per cent.

(*d*) 15 per cent contours from thirteen β-diagrams from sub-areas adjacent to granite.

(*e*) Poles of 266 foliation surfaces ; full circle, axis of girdle ; contours, 1–3–5–7 per cent.

(*f*) Axes of forty-seven small folds ; contours, 2–5–15 per cent.

(*g*) Axes of thirty-six lineations ; contours, 2–5–15 per cent.

(*h*) 15 per cent contour lines from twelve β-diagrams from sub-areas within granite.

which plunge gently north-north-east is not, however, thus explained. These structures are restricted to three small areas at Carnloch, Easter Duthil, and Laggan Hill, and at each locality they are found in juxtaposition to south-easterly plunging folds. The north-easterly plunging folds are overturned from the south-east but are otherwise identical in character to the folds of regional trend. There is no evidence available from which it can be inferred that the folds of the two trends formed at different times. Whatever the origin of the few north-easterly plunging folds their presence invalidates neither the structural generalizations made here nor structural profiles previously published (e.g. in McIntyre, 1951).

The area has been divided into numerous sub-areas for which the β-axes have been determined. In this way slight variations in structural homogeneity can be detected with some confidence. Text-fig. 2*d* shows the 15 per cent contour lines from the β-diagrams of sub-areas immediately adjacent to the granite. In sub-areas containing insufficiently variable foliation attitudes for the determination of β-axes the most constant structural element is the average foliation surface which is represented by the great circle normal to the π-pole maximum. Such surfaces are indicated in the appropriate sub-areas on Text-fig. 3. In common with the small folds and the lineations the trend of the β-axes in the country rocks of the whole area swings round from east in the north-east to south-south-east in the south-west.

The fold style in Mid-Strathspey is generally monoclinal to slightly recumbent, all the folds being overturned from the north-east whether in the country rocks or in the included blocks. Occasional "coffin-shaped" or markedly recumbent folds are restricted to rocks such as marbles or migmatites which were rather plastic during deformation, but within the granite inclusions of migmatite are rare and marble blocks have not been found.

The regional swing in the trend of axial structures means that the structural homogeneity in the sub-areas close to the Grantown Granite is somewhat greater than that shown in Text-figs. 2*a*, *b*, and *c*.

The Structure of the Inclusions in the Granite

The presence of a large number of inclusions all characterized by the structures common in the country rocks suggest that the geometrical and statistical methods used in the study of folded rocks would be the most suitable for a study of the interior of the granite. These methods are usually applied to foliated rocks to demonstrate areas of homogeneity of fabric. Conversely, there is no valid objection to their use to show degrees of structural inhomogeneity, as is done below, even though the inclusions are separated from one another by granite. The sub-areas are rather arbitrarily defined, mainly by absence of

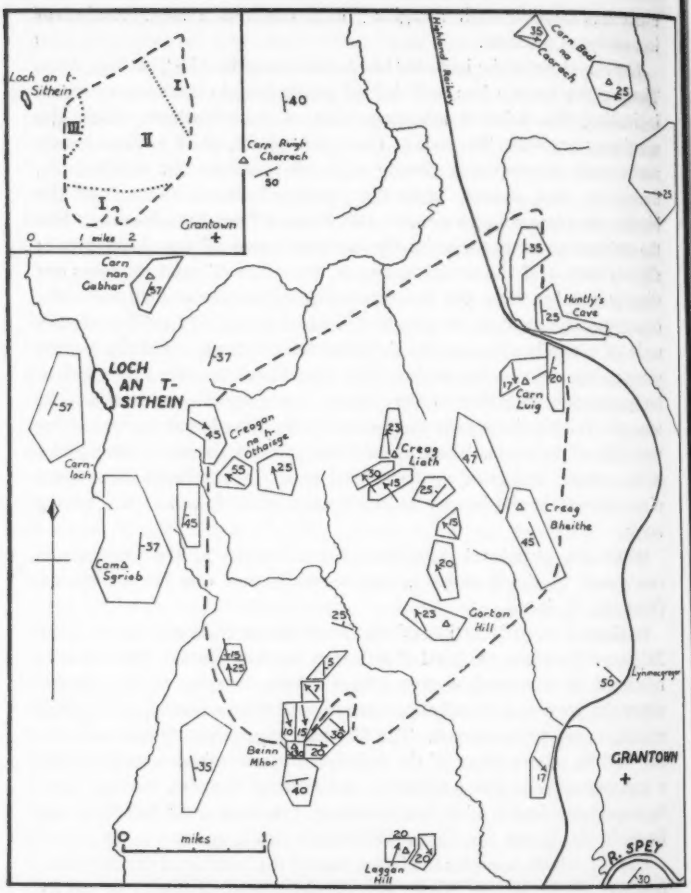
exposures beyond their margins; each contains a large number of inclusions of all sizes.

The structure of the included blocks is summarized by Text-figs. 2*e–h*. The π-poles form a less well defined girdle than in the country rocks, indicating the relative inhomogeneity of the structure within the granite as a whole. The axis of the π-pole girdle, which plunges gently north-west, corresponds closely with the maxima for small folds, lineations, and β-axes, while the average foliation surfaces of the blocks are planes which contain the *B*-axes of nearby sub-areas. For the sub-areas in the granite the average value of the β-maxima is slightly less, and the apical angles of the cones of axial elements are slightly greater, than the corresponding values determined from the country rocks around the granite (cf. Mackenzie, 1957). Thus on the scale of a single sub-area the fabric of the blocks is relatively homogeneous whereas on the scale of the whole complex this fabric is less homogeneous than that of the country rocks for a considerable area around. Within the granite the β-maxima decrease in value towards the west side of the mass. The style of folding in blocks and country rocks is the same. Folds of up to several yards in amplitude have been observed within the blocks and their axial plane foliation dips gently north.

When the structural data from the sub-areas in the granite are considered in detail three zones of orientation can be recognized (Text.-fig. 3, inset).

In Zone *I* the orientation of the *B*-axis in the blocks is up to about 30° away from the regional *B*-axis in a vertical plane. This zone is restricted to the north-eastern and southern margins of the granite where the contact is usually concordant with the country rock foliation and dips east or south-east. The fold axes plunge gently south-south-east and lie in the plane of the foliation surfaces whose π-poles mark a concentration in the north-west quadrant of Text-fig. 2*e*. As is to be expected blocks with horizontal or sub-horizontal foliation are found in this Zone—on Gorton Hill and Carn Luig.

Zone *II*, which occupies the larger part of the interior of the complex, contains blocks whose *B*-axes plunge north-west at angles of up to 30°. These inclusions have been rotated from the position of the regional fold axis by from 30° to 60° in a vertical plane. The average foliation surfaces in this zone dip north-west at moderate angles or steeply west-south-west. The sub-areas on Creag Bheithe would appear to be the continuation in the granite of the area of steep south-westerly dipping foliation in the country rocks at Lynmacgregor. In view of the fact that structural measurements were taken from a great number of inclusions, the homogeneity of fabric in this zone is remarkable, equalling in constancy that in the sub-areas of the country



TEXT-FIG. 3.—Structural map of the Grantown Granite with zones of orientation (inset). Granite contact, heavy broken line; sub-areas outlined by full thin lines. β-axes (arrows) and average foliation surfaces (dip and strike signs) shown in appropriate sub-areas. Foliation in isolated exposures shown by dip and strike signs outwith sub-areas.

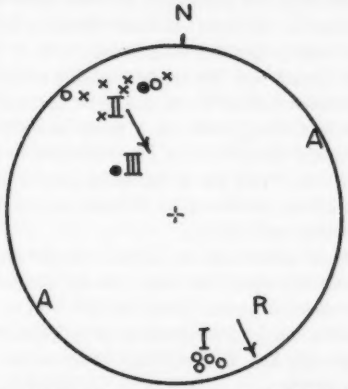
rocks. Towards the west side of the zone the β-maxima are weak, indicating increased departure of the foliation surfaces from the ideal within individual sub-areas.

Zone *III* consists of one sub-area at the western margin of the granite, where the contact is steep. The *B*-axis plunges steeply to the

north-west and the β-maximum is weak. Here the *B*-axis in the blocks has been rotated by from 60° to 90° from the position of the regional fold axis. One sub-area lies astride the western contact zone of the granite and contains a weak β-axis plunging at 45° to the south-east. The dip of the average foliation surfaces in sub-areas west of the granite is generally steeper than the regional dip of 30°.

Discussion

The similarity in fold style and symmetry of the foliated rocks inside and outside the granite, the continuation of areas of similar dip and strike across the granite contact at Creag Bheithe, and the fact



Text-fig. 4.—Generalized geometrical rotation of blocks in the Grantown Granite illustrated by rotation of β-axes (lower hemisphere equal area projection). *R*, regional fold axis; open circles, β-axes of Zone *I*; crosses, β-axes of Zone *II*; full circles, β-axes of Zone *III*. Arrows show sense of geometrical rotation.

that in Mid-Strathspey (and in a wide area beyond) north-west plunging folds are to be found only within the granite, all indicate that prior to the emplacement of the granite the blocks now in the granite were oriented with their *B*-axes plunging south-east at about 30°. Although the foliation in the country rocks and the included blocks has roughly the same strike (see quotation, p. 57), the dip is in opposite directions, i.e. the included blocks have a general dip to the west and north-west. This unusual situation would not have appeared so to Hinxman and Anderson, who considered that the country rocks were folded about sub-horizontal axes treading north-east (1915, pp. 18, 22).

The progressive rotation of the blocks from their original position is illustrated by the rotation of the β-axes from *R* through *I* and *II* to *III* in Text-fig. 4. The axis of this generalized rotation, *A*, is sub-

horizontal and trends north-east. But rotation is here used in a geometrical and not a kinematic sense. The sense of geometrical rotation of the blocks is anticlockwise to an observer looking north-east along the rotation axis, because by comparison of the fold styles and the sense of overturning the upper surfaces of folia and folds in the country rocks are seen to correspond to the upper surfaces of folia and folds in the inclusions. Thus kinematically there was external rotation of large and small blocks in the granite.

There must have been considerable movement of the blocks in the granite to allow them to take up their present positions. However, the regular pattern of dispersion both of the *B*-axes and of the axial plane foliation suggests that the inclusions did not move solely by gravitation but were aided in transport to their positions by mass movement of the granite itself; this movement was not of such strength or direction as to disturb the bordering country rocks at all violently. This lack of boundary disturbance could be accounted for by postulating movement of the granite in a plane parallel to the regional foliation surface and therefore in a plane parallel to the longer visible axis of the complex. With the evidence at present available it is not known to what extent movement of the granite and its inclusions may have been reciprocal and relative.

The regularity of orientation in Zone *II* is perhaps due to the fact that the zone contains a few very large blocks separated by both thick and thin planar granite sheets along the foliation, a condition which would result in the maximum retention of cylindroidality. Lit-par-lit occurrence of granite has, in fact, been observed on a small scale in this, and other, zones.

In the absence of a recognizable penetrative structural element in the granite itself the kinematic picture must remain incomplete. The results can be summarized by stating that the displacement in the attitude of the blocks is progressively greater towards the west side of the complex. Petrographic similarity of inclusions to country rocks indicates that movement of the blocks in a vertical direction was probably not great.

Although internally the complex consists of a reticulate network of sills and dykes of a wide range of thicknesses, the external outline of the mass is lenticular and concordant with the country rock foliation. The inclusions are disposed in an arch but the wall-rock foliation is not. Thin granite veins cutting the country rocks show that there was dilation of the latter on a small scale. Dilation on a large scale is not easy to prove, but the curving of the strike of the country rocks around the mass suggests that there has been dilation on a large scale, a feature considered by some, for instance, Leedal (1952, p. 39), to be typical of Scottish granites of Caledonian age. The large number

of inclusions throughout the visible depth of the complex suggests that the roof of the granite lay not far above the present surface. There is no direct evidence to show that the zones of orientation are equivalent to zones of depth beneath the roof of the mass, although the concordant dip of the eastern contact implies that granite was emplaced higher in the crust on the west than on the east.

From the lack of a contact metamorphic zone it can be inferred that the Grantown Granite was emplaced at a temperature of the same order as that of the country rocks. The gneisses and schists of Mid-Strathspey bear mineral assemblages typical of the lower amphibolite facies (diopside marbles, kyanite gneisses and garnet amphibolites) and this facies has been taken to have a temperature range of the order of 400–500° C. (Ramberg, 1952, p. 137). The disorientation of inclusions discussed above shows that the granite was more plastic than the blocks during emplacement. The evidence of arrested breakdown of some feldspar crystals implies that there was cataclasis during the emplacement stage although there was no tendency for the granite to take on a directed structure. Thus a fairly low degree of absolute plasticity comparable with that of a solid rather than a liquid is envisaged for the granite at this stage. Much of the crystallization of the rock, however, was completed after emplacement. While all the above evidence throws light on the nature and conditions of emplacement of the granite the place and process of generation of the granite remains a matter for speculation. A clue to the deciphering of the early history of the granite is provided by the zoning of the plagioclase, a feature which has been used above to make kinematic rather than petrogenetic inferences.

Rotated inclusions in granite masses have been recorded and discussed by several authors (e.g. Lelubre, 1938 ; Cogné, 1950 ; Pitcher, 1952 ; Perrin and Roubault, 1952 ; Perrin, 1954, 1956). In his study of some of " the relatively rare cases of so-called displaced inclusions, i.e. with discordant schistosities, suggestive of displacement by a liquid ", Perrin (1956, p. 12) has devised a series of explanations for displaced and rotated inclusions, such as the development of new schistosity in a non-rotated inclusion, or the granitization of a folded migmatite, or of lavas containing inclusions, or of tectonic breccias. However valid each of these explanations may be in particular instances, the Grantown Granite furnishes clear-cut examples of rotated inclusions which appear to the writer to be inconsistent with formation of the granite in situ, but consistent with emplacement of the granite by dilation of the country rocks. The sole physical requirement of rotated inclusions is that at the time of intrusion the granite was more plastic than the inclusions.

The application of statistical structural methods to inclusions in

granitic rocks as has been done above, while perhaps limited, is greatly to be desired before inferences are made regarding the mode and conditions of emplacement of the granite.

ACKNOWLEDGMENTS

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GEOLOGICAL SURVEY DEPARTMENT,
NEW ENGLAND,
FREETOWN.
SIERRA LEONE.

A Cambro-Ordovician Fauna from the Hecla Hoek Succession of Ny Friesland, Spitsbergen

By A. Hallam

Abstract

A short description is given of Cambrian and Ordovician fossils from near the top of the Hecla Hoek succession in Ny Friesland and the relations with other areas is briefly discussed.

I. Introduction

THE stratigraphy of the Hecla Hoek succession in north-east Vestspitsbergen, which comprises a thick series of late Precambrian and Lower Palaeozoic sediments, was recently outlined by Harland and Wilson (1956). They divided the succession into three major groups. The highest of these, the Upper Hecla Hoek Group, is further subdivided into the Polarisbreen and the Oslobreen Series. During the Cambridge expeditions of 1953 and 1955 a small number of fossils was collected from the Oslobreen Series. Dr. C. Poulsen identified some specimens from the Oslobreen Dolomites as *Salterella* cf. *rugosa* Billings and Professor W. B. R. King tentatively suggested that trilobites from the overlying Oslobreen Limestones were of Upper Cambrian age. On this basis the Oslobreen Series was provisionally dated as Cambrian. Further material was collected in 1956. In the present work the fauna is described for the first time and this shows the Series to have a greater age range than first suggested. The writer is indebted to Mr. W. B. Harland for suggesting the study and for his helpful comments; to Mr. C. B. Wilson, who made the collections, for stratigraphical information, and to Dr. J. W. Cowie for valuable comments on the reliability of some determinations and correlations.

II. Description of the Fauna

With the exception of *Salterella* all the fossils were collected from the Oslobreen Dolomites and the Lower and Middle Oslobreen Limestones in lower Oslobreen. The material is inadequate to warrant detailed description and the remarks in the following notes are confined to discussion of the features by which the fossils were identified. The numbers refer to specimens in the Sedgwick Museum collection unless otherwise stated.

Trilobita

Genus Hystricurus Raymond, 1913

Hystricurus aff. *flectimembrus* Ross

Hystricurus flectimembrus Ross, 1951, p. 48, pl. 10, figs. 25, 26, 29–33; pl. 11, figs. 16–18, 20–33

Material.—Five cranidia ; five free cheeks ; one pygidium ; isolated thoracic pleurae. A46782–94.

Remarks.—Ross's species is easily distinguished by the flexed postero-lateral limbs of the free cheeks and by the almost semi-circular palpebral lobes. It occurs in the Lower Canadian of Utah. In the Spitsbergen material there is very close agreement in most characters though the proportions of the glabella differ slightly, but this difference might well be only varietal.

Horizon.—Band in Lower Oslobreen Limestones about 90 m. from the base.

Hystricurus ? sp.

Material.—One partly eroded cranidium. A46781.

Remarks.—This differs from *H. flectimembrus* most strongly in the position of the palpebral lobes.

Horizon.—Associated with *H.* aff. *flectimembrus.*

Genus Bolbocephalus Whitfield, 1890

Bolbocephalus cf. *seelyi* (Whitfield)

Bolbocephalus seelyi (Whitfield) ; Whittington, 1953, p. 655, pl. 66, figs. 1–10, 12–14, 17, 21, 22, text-fig. 2

Material.—One partial cranidium, A46795, showing most of glabella, occipital furrows, and a small part of the left fixed cheek.

Remarks.—There is good agreement in size and shape with the figures of Whittington, who has redescribed Whitfield's material, though the glabella expands perhaps a little more towards the anterior than in the true *seelyi.* Distinctive features include the inflation of the inner, posterior portion of the fixed cheek and the narrowing of the glabella in front of the occipital ring. The external surface of the glabella is smooth like that of *B. groenlandica* Poulsen. Whittington gives the range of the genus as Middle to Upper Canadian and the species as Upper Canadian.

Horizon.—Middle Oslobreen Limestones.

Genus Bathyurellus Billings, 1865

Bathyurellus ? sp.

Material.—Two partial free cheeks and a pygidium. A46796–7.

Remarks.—This form is reasonably close in some respects to

B. teicherti Poulsen, 1937, p. 53, pl. 7, figs. 2–5. Thus, the anterior portion of the preglabellar field passes laterally into a groove on the genal spines. However, the characteristic surface ornament is not visible, the genal spines are more elevated and wider at the base, the pygidium is wider, and the pleural furrows of the latter more strongly marked.

Horizon.—Middle Oslobreen Limestones.

Bathyurids

Material.—A number of fragmentary and partly-crushed free cheeks, thoracic pleura, and a pygidium. A46798–800.

Remarks.—The free cheeks have a shape characteristic of most members of the Bathyuridae, a Lower Ordovician family discussed by Whittington (1953). All have lateral grooves, which in A46798 pass anteriorly into a concave preglabellar field as in *Bathyurellus teicherti.* The pygidium is somewhat doubtful.

Horizon.—Middle Oslobreen Limestones.

Indeterminate fragments

Material.—Fragments include a free cheek, several pygidia, and a thorax. W 1048, 1060, 1065, 1400, 1422, 1425, 1427, 1434. These numbers refer to specimens in the Spitsbergen Collection in the Sedgwick Museum.

Brachiopoda

Genus Obolus Eichwald, 1829

Obolus sp.

Material.—Thirty-eight specimens, mostly fragmentary, including both dorsal and ventral valves. A46801–16.

Remarks.—The material is poorly preserved and cannot be accurately identified. The most notable feature is the fine radial ribbing of the exfoliated surface of the valves. The outer surface of the shell bears in contrast only the faintest radial striations.

Horizon.—Most of the specimens were found in the upper half of the Oslobreen Dolomites at the same horizon as *Salterella.* A few (W1047, W1049, W1409, W1415) were found in the Oslobreen Limestones.

Genus Archaeorthis Schuchert and Cooper, 1931

Archaeorthis groenlandica Poulsen

Archaeorthis groenlandica Poulsen, 1937, p. 42, pl. 4, figs. 1–4

Material.—Nine specimens including both pedicle and brachial valves. No internal structures visible. A46817–24.

Remarks.—There is good agreement with Poulsen's figures.

A. elongata Ulrich and Cooper is close. The genus is Canadian in age.

Horizon.—Middle Oslobreen Limestones.

Gastropoda

Genus MACLURITELLA Kirk, 1927

Macluritella ? sp.

Material.—Numerous small specimens preserved as internal moulds on five pieces of limestone. Most project out of the rock only partially. A46825–34.

Remarks.—This species is a loosely coiled form bearing some resemblance to *M. stantoni* Kirk (Knight, 1941, p. 184, pl. 66, figs. 2*a–d*) which is recorded from the Lower Ordovician of Colorado. However, the increase in whorl cross-section is slower and there are more turns without a rapid increase in diameter.

Horizon.—Lower Oslobreen Limestones, associated with *Hystricurus* aff. *flectimembrus.*

Genus HELICOTOMA Salter, 1859

Helicotoma ? sp.

Material.—Three small partly eroded specimens. A46835–7.

Horizon.—Middle Oslobreen Limestones.

Cephalopoda

Genus SALTERELLA Billings, 1865

Salterella cf. *rugosa* Billings

Salterella rugosa Billings ; Poulsen, 1932, p. 32, pl. 7, figs. 11–15, pl. 8, figs. 1–2 ; text-figs. 5–6.

Material.—Numerous specimens on three pieces of limestone. A46838–40.

Remarks.—This form, as noted earlier, was identified by Poulsen. Its age is regarded as Lower Cambrian.

Horizon and Locality.—Oslobreen Dolomites, Lower Polarisbreen, and west face of Andromedafjellet.

III. AGE OF THE OSLOBREEN SERIES

The Oslobreen Series has a thickness of at least 1,400 m. (Harland MS.) and consists predominantly of carbonate rocks. Above a thin sandstone at the base, which is taken provisionally as the beginning of the Cambrian, come the Oslobreen Dolomites, 160 m. thick. These are overlain by the Oslobreen Limestones, subdivided into Lower (180 m.), Middle (250 m.), and Upper (800 m.) parts.

Dating of the Oslobreen Dolomites can be achieved by a comparison with East Greenland. Here *Salterella rugosa* is recorded from the Ella Island Formation of late Lower Cambrian age (Poulsen, 1932 ; Cowie and Adams, 1957), where it occurs associated with a rich trilobite fauna. It is also found in the overlying and otherwise unfossiliferous Hyolithus Creek Formation, which Cowie and Adams hesitate to date. The Oslobreen Dolomites can be taken as Lower Cambrian ; possibly they are the equivalent, in part, of the Hyolithus Creek Formation.

There is no doubt that the fauna of the Oslobreen Limestones is Lower Ordovician (Canadian) in age. The bathyurid-*Archaeorthis* fauna of the Middle Oslobreen Limestones is perhaps to be correlated with part of the Kap Weber Formation of East Greenland which is Upper Canadian and contains *Archaeorthis groenlandica* and many trilobites including species of *Bolbocephalus* and other bathyurids (Cowie and Adams, 1957). The Upper Oslobreen Limestones may eventually yield younger Ordovician faunas.

In fixing the base of the Ordovician it should be borne in mind that there is no trace in this Spitsbergen material of lowest Ordovician ("Ozarkian") faunal elements such as occur in the Cass Fjord Formation in Greenland. This fauna is characterized by species of *Hystricurus* and *Symphysurina* and by the gastropod *Sinuopea whittardi* (Poulsen, 1937).

In summary, the Oslobreen Dolomites are at least partly Lower Cambrian while the Middle and most of the Lower Oslobreen Limestones are Lower Ordovician.

IV. Discussion

A number of interesting matters arise that deserve mention. In the first place the small thickness of strata between the highest *Salterella* and *Hystricurus* aff. *flectimembrus* horizons is noteworthy. If there are no important breaks the whole of the Middle and Upper Cambrian and the bottom part of the Ordovician must be accommodated within little more than a tenth of the total thickness of the Oslobreen Series.

Secondly, there is surprisingly little faunal comparison with the neighbouring Hecla Hoek rocks of southern Spitsbergen and Bear Island. In the former area Major and Winsnes (1955) have described a Lower Cambrian trilobite fauna found in loose boulders and a Lower Ordovician fauna of cephalopods and gastropods. In Bear Island a predominantly cephalopod-gastropod fauna of Lower and Middle Ordovician age has been collected (Holtedahl, 1920). It is, of course, quite possible that the lack of faunal elements common to these different regions is due to insufficient collecting.

Poulsen (1951) has pointed out the close faunal similarities of the

Cambro–Ordovician of East Greenland, the St. Lawrence, and the North Scottish Provinces and has emphasized the striking lithological resemblances of the limestone successions of East Greenland and the Durness Limestone. These resemblances may be extended to Spitsbergen. While the cephalopod–gastropod faunas of southern Spitsbergen and Bear Island invite comparison with the Durness Limestone the Ny Friesland region shows strong similarities to East Greenland. In both areas Cambrian dolomite rocks are overlain by Ordovician limestones and dolomitic limestones. Both successions contain abundant intraformational conglomerates. Moreover, no Middle or Upper Cambrian fossils have been discovered anywhere in the triangle marked out by North Scotland, East Greenland, and Spitsbergen. However, this broad similarity should not obscure differences of detail. Thus, *Hystricurus* aff. *flectimembrus* has not been recorded from Greenland while the Lower Cambrian trilobite fauna and the Lower Canadian *Sinuopea whittardi* fauna of East Greenland have yet to be found in Ny Friesland. As already noted, a close tie-up with southern Spitsbergen is not yet possible. It is hoped that further expeditions will enable a more complete description of these rocks and their faunas to be made.

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SEDGWICK MUSEUM,
CAMBRIDGE.

A note on new Namurian plant localities at the head of the Neath Valley, South Wales

By D. G. Jones

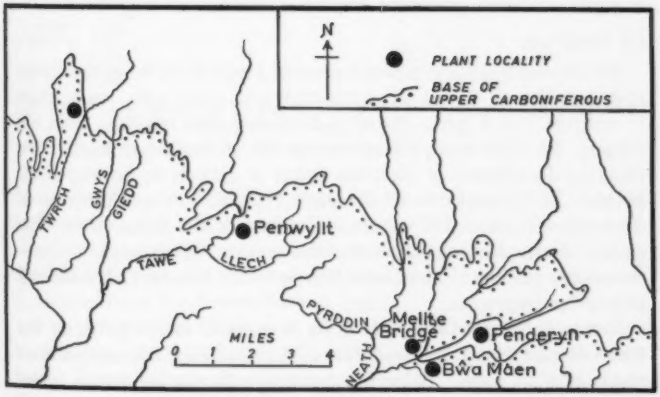
Abstract

The occurrence of low Namurian plants in the Neath Valley is noted. It is believed that they show the presence of the *Eumorphoceras* Stage. This revision of age in relation to the Namurian–Avonian junction is briefly discussed.

Introduction

GONIATITES older than the R_1 Stage of the Namurian are not known to occur east of the Twrch Valley on the North Crop of the South Wales Coalfield, and the determination of the age of the lowest Namurian strata has depended to a large extent on the presence of plant horizons. Floras of low Namurian type on the North Crop have been recorded and described from the Twrch Valley by Ware (1939, p. 175) and by Robertson (1933, p. 242) and Dix (1933, p. 158) from the Penwyllt area at the head of the Swansea Valley (Text-fig. 1).

The presence of *Lyginopteris* (*Calymmatotheca*) *stangeri* (Stur) 10 feet above the Carboniferous Limestone/Millstone Grit junction at Mellte Bridge on the north side of the Dinas Fault has been noted by Owen and Jones (1955, p. 463). Plants have also been found at a similar distance above the junction near Bŵa Maen on the south side of the fault, 650 yards due east of Mellte Bridge. This discovery has already been recorded (Jones and Owen, 1957, p. 236) but an exact



Text-fig. 1.—Low Namurian plant localities on the North Crop of the South Wales Coalfield.

correlation was not then certain. Recently the writer discovered the same plant horizon at a locality near Penderyn, 2½ miles E.N.E. of Mellte Bridge and the age and significance of the plant occurrences is discussed below.

The Plant Localities

(*a*) *Mellte Bridge.*

The occurrence of *L. stangeri* at this locality has been noted previously and little more may be added beyond the occurrence of the form in a 3 ft. band of coaly shale and underclay with *Stigmaria* 10 feet above the D_2 Zone of the Avonian.

(*b*) *Bŵa Maen.*

The plants are here found in a band of dark shale, 1 foot thick, sandwiched between hard quartzites and lying 12 feet above the base of the Millstone Grit in the gorge of the River Sychryd near the silica levels.

The forms present include:—

Sigillaria sp.
Mesocalamites sp.
Sphenophyllum tenerrimum Ett.
Diplotmema adiantoides (Schloth)
Lyginopteris fragilis (Schloth).

The height of this bed above the Avonian is similar to the *L. stangeri* bed at Mellte Bridge, but the underlying limestones are of different ages, D_2 at Bŵa Maen and D_3 at Mellte Bridge. It is probable, however, that the same plant horizon is represented in both cases.

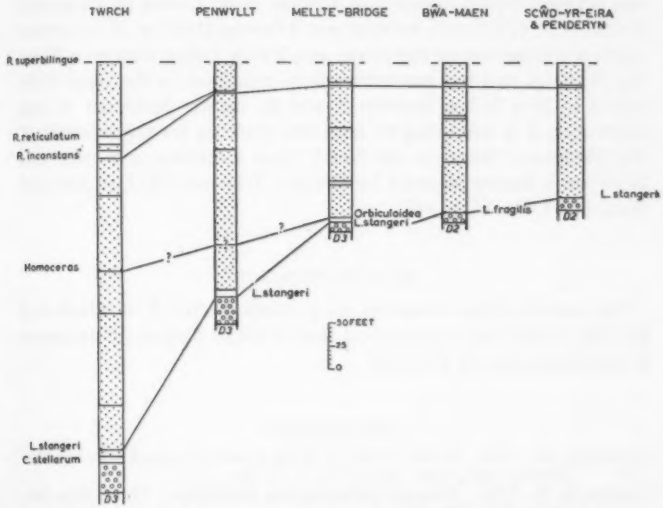
(*c*) *Penderyn.*

The exposure yielding plants is situated ¼ mile W.N.W. of the village and consists of 5 feet of weathered underclay with coaly shale (" rashings ") and grits. It lies in a marked cleft resulting from old diggings for silica sand, almost on the line of the Dinas Fault. The resulting disturbance of the beds makes it difficult to determine the position in the sequence of the plant horizon. A consideration of thickness suggests it lies very near the base of the Basal Grits. The shales associated with the underclay contain *Lyginopteris* (*Calymmatotheca*) *stangeri* in abundance together with obscure Calamitid and Stigmarian fragments.

A thin band of black coaly shale is exposed in the gorge of the River Hepste below the waterfall of Scŵd-yr-Eira but contains no plants of zonal value. It lies 4–5 feet above the Carboniferous Limestone (D_2) and from its position is probably the same horizon as occurs at the other Vale of Neath localities.

The Age of the Plant Horizons

The forms occurring in the Vale of Neath have also been recorded by Dix (1933, p. 163) from Penwyllt and the complete florule of which they form a part was regarded by her as " occurring not above the base of the *Homoceras* zone ". In Carmarthenshire, Ware (1939, p. 201) noted the occurrence of *L. stangeri* in close association with a bed yielding *Cravenoceratoides stellarum*, and concluded that the plant was the principal constituent of floras of the *Eumorphoceras* Stage. Moore (1941, p. 286), in a comprehensive discussion on the presence of the



TEXT-FIG. 2.—Correlation of marker horizons in the Basal Grits between River Twrch and Penderyn.
(Twrch after Ware, Penwyllt after Robertson and Dix)

Namurian in the Bristol district, regarded *D. adiantoides* and *L. fragilis* as indicative of a low Namurian (*E*) age. The recent researches of Currie (1954, p. 532) on the goniatite sequence in Scotland show that Kidston (1923–25) and Crookall (1939, p. 13) obtained *L. fragilis* and *L. stangeri* from the *Eumorphoceras* Stage.

A similar vertical distribution of the above forms has been noted by Patteisky (1935, p. 732) in an account dealing mainly with Silesian floras. More recently Stockmans and Williere (1954, Table 4) have shown that *L. stangeri* is characteristic of Namurian A in Belgium and again occurs in the *E* Stage at many localities. Further evidence of

the low occurrence of the form is also to be seen in its presence in strata of P_2–E_2 age in Ireland (Robbie, 1955, p. 26).

In view of the known range of these forms elsewhere there seems little doubt that their occurrence denotes the presence of the *Eumorphoceras* Stage in the Neath Valley and at Penderyn. This reduces the amount of easterly directed intra-Namurian overlap and also the amount of diachronism at the base of the Basal Grits between the Neath and Twrch valleys. The major differences in the grits over this area are now ascribed to eastward thinning, with the probable existence of several minor breaks in the sequence rather than a major one between the Namurian and Avonian as postulated by Evans and Jones (1929, p. 175) and Robertson and George (1929, p. 38). Furthermore, a comparison of the Neath and Twrch Valley sequences (Text-fig. 2) shows that the greatest westerly expansion in the Basal Grits occurs in beds falling between *E* and R_1 marker horizons; in this connection it is interesting to note that evidence for the existence of the *Homoceras* Stage on the North Crop is known only from two localities, a feature recorded by Dix and Trueman (1932, p. 326) and Ware (1939, fig. 11, p. 187).

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DEPARTMENT OF GEOLOGY,
KING'S COLLEGE,
LONDON, W.C. 2.

CORRESPONDENCE

A USE FOR ACETIC ACID IN THE STUDY OF FOSSIL SPONGES

SIR,—Most of the macroscopic skeletal remains of sponges which occur in the Upper Cretaceous rocks of Great Britain and Northern Ireland represent members of the classes Demospongia and Hexactinellida, in which the spicules are siliceous. It has long been known (cf. Zittel, 1877) that skeletons of this sort can be extracted from calcareous matrices by use of nitric or hydrochloric acids, provided that they are still in a siliceous condition. Material suitable for treatment in this manner is unfortunately not usual in the British outcrops, being generally restricted to the *Schloenbachia varians* Zone of southern England and the *Inoceramus lingua* Zone of Yorkshire. Most other chalk specimens, other than those imbedded in flints, have the skeletal meshwork represented by limonitic material or by hollow moulds in the matrix, or by a combination of both. They are thus generally unsuitable for acid preparation, and have to be extracted mechanically in consequence. There is, however, one type of non-siliceous preservation in which a chemical method can be used. At certain horizons the English and Irish successions contain accumulations of phosphatized sponge remains; that is, of specimens in which the matrix which fills the skeletal meshes is impregnated with phosphatic material. The principal occurrences of specimens of this sort are in the Glauconitic (" Chloritic ") Marl of southern England, in the Chalk Rock from Berkshire to Cambridgeshire, and in the Glauconitic (" Chloritic ") Chalk of Co. Antrim, Northern Ireland. In the Glauconitic Marl the phosphate is dark brown, dark grey, or black; in the other cases it appears to be of a different type, being typically pink in colour with gradations to yellow or light brown. The skeletal framework is typically represented by hollow moulds, which sometimes contain rod-like internal casts of the axial canals of the spicules. In all the cases cited the sponges are mainly dictyonine Hexactinellida, though lithistid Demospongia may also occur. Specimens of this type are suitable for treatment with acetic acid; because of the differential solubility in this acid of the phosphatized intra-skeletal matrix and the unphosphatized surrounding sediment respectively, it is possible to dissolve away the latter, at a speed suitable for practical use, without affecting the former. As a result, in spite of the absence of actual skeletal meshwork, the specimens can be extracted in the form of sponge pseudomorphs, with matrix cleared from external surfaces, and also from internal circulatory spaces unless it is phosphatized within them.

The details of procedure are as follows. The specimens are placed in a dish or trough, which should be deep enough to allow their complete immersion to at least 1 inch depth. If possible, use an acid-resistant rack, by means of which they can be lifted out. They are then covered with acetic acid in 20 per cent aqueous solution. No advantage seems to be gained by using a weaker solution, but acid of much greater strength may cause crumbling of the phosphatized material. The specimens are removed after three or four hours and examined individually to check suitability for further treatment; poorly phosphatized examples are liable to crumble whatever strength of acid is used, and any showing this tendency extensively should be rejected. Those replaced in the acid should be examined again a day later. After this, they can be left till all unphosphatized material is dissolved. During this stage, additional mechanical preparation may also be helpful. Clearing of sand or glauconite grains from surfaces should be effected with a fine water jet or a soft toothbrush; hard brushing or scraping destroys traces of the skeletal structure. If matrix in internal cavities is also phosphatized, it may be found to become softened by the acid; it can then be worked out at intervals with a knife-blade or needle, care being taken not to touch the sponge surfaces in this process. When extraction is finished,

specimens need to be cleared of acetate by immersion in water for about a week; running water does not seem necessary provided that changes are made at daily intervals. After this immersion specimens are dried and examined for acetate growths, any showing these requiring further soaking. Once cleared satisfactorily, the material is ready for study or storage. If desired, examples which appear fragile can be strengthened by spraying with dissolved plastic, e.g. Lustrex in benzene.

This technique has been developed mainly for dealing with material from the Chalk Rock and Glauconitic Chalk. It has proved specially valuable in the case of the latter formation, which is often difficult to treat mechanically because of hardness and a considerable content of mineral grains. The same technique is, of course, equally applicable to other phosphatic fossils, such as e.g. the ammonites which occur in this condition in some Cenomanian deposits.

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R. E. H. REID.

GEOLOGY DEPARTMENT,
QUEEN'S UNIVERSITY,
BELFAST.

9th December, 1957.

ON SOME TURKISH SEDIMENTS

SIR,—I recently spent a month in Turkey, and through the kindness of various Turkish geologists was able to see a little of the local geology. Without pretending to be an authority on either country, I would like to draw attention to the remarkable similarity of certain geological features in Turkey to those I described recently in a report of an excursion in Italy (Ager, 1956). Particularly notable is the presence in Turkey of large areas of confused mixed sediments comparable to the Italian *Argille scagliose*. These Turkish formations have received various names, e.g. the "exotic block series", the "série mixte", the "complexe à facies tectonique brouillé", and so on; Blumenthal has called them the "Türlü Güveç" (a Turkish version of Lancashire hot-pot). Exotic blocks found in this mixture include serpentines and pillow-lavas and are recorded as yielding fossils ranging in age from Permian to Cretaceous. Very thick Oligocene and Miocene sedimentation in Turkey is another feature reminiscent of the north Apennine area.

A great deal of work in Turkey has been done by nappe-minded geologists. A non-tectonician may be allowed to wonder if much of the confused geology of Turkey might be explained in terms of tectonic ridges and submarine land-slipping, as in Italy. At Şile on the Black Sea coast, north-east of Istanbul, I saw a fine section of brecciated Upper Cretaceous limestone resting on Eocene nummulitic marls. This has been described by Baykal (1943) as a thrust, with the very coarse breccia as a mylonite. This interpretation has been disputed by other workers, and the section appeared to me to show all the characters of a gravity collapse structure. I made these suggestions to various Turkish geologists and my attention was drawn to a paper by McCallien and Tokay (1951). In this, exotic Carboniferous blocks in the Cretaceous, on the Black Sea coast between Zonguldak and Ereğli, are explained by submarine slumping due to earthquakes. In the discussion of this paper the late Professor C. I. Migliorini commented on the close resemblance of the Turkish photographs to the *Argille scagliose* of the Apennines.

Another point worth recording is that just west of Şile is a small promon-

tory of completely typical white chalk with flints and fossils such as *Micraster*, *Echinocorys*, and *Porosphaera*. This has simply been described as Maestrichtian " calcaires blancs . . . à nodules de silex " (Baykal, op. cit., p. 201), but is virtually the same as the familiar Upper Chalk of north-west Europe. This facies appears to have only reached Turkey late in Maestrichtian times. Lower down there are whitish sandy limestones, marly limestones, and some pink limestone reminiscent of the Hunstanton " Red rock ". Palaeogeographical maps show the Chalk sea reaching no farther than the Crimea and the Caucasus in a south-easterly direction (e.g. Wills, 1951, Pl. XVIII).

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D. V. AGER.

IMPERIAL COLLEGE,
LONDON, S.W. 7.
20th November, 1957.

RECENT MARINE DEPOSITS NEAR BASRAH

SIR,—I have read with unusual interest the paper by Hudson *et al.* (1). Their conclusions support the contentions of Lees and Falcon (2) regarding recent movements within the lower Mesopotamian Plains, and I likewise have reasons for accepting these views (3).

The above authors mention that so far the only evidence for the Hammar Formation north of Basrah is that given by Macfadyen (quoted by Lees and Falcon), who reported marine foraminifera in " alluvium " at Amara, 95 miles N.N.W. of Basrah, occurring at depths of 3 to 35 feet. It is pertinent to refer to recent studies in the vicinity of Najaf, some 220 miles north-east of Basrah and 160 miles due west of Amara.

Beside the Wadi Ruhaimawi, approximately 15 miles W.S.W. of Najaf, a bore-hole was sunk to a total depth of 26 feet. At depths between 23 feet and 25 feet an interesting fauna was found in some brownish silty clays, including *Turritella terebra* Lamarck (juv.), *Retusa inconspicua*, *Natica sp.*, *Minolia sp.*, *Dentalium sp.*, *Corbula sulculosa*, *Ostrea sp.*, and some echinoid plates. On faunistic grounds, therefore, these silty clays correlate well with the Hammar Formation.

The Basrah specimens were found at depths of 13·4 to 34·4 feet below present mean sea level ; the Amara foraminifera from 7 feet above sea level to 28 feet below sea level ; the Najaf fauna occurred at elevations of 133·5 of 135·5 feet above present mean sea level. This vertical range of some 170 feet between the southern and northern fossil occurrences is scarcely due solely to vertical land movements, and regional change in sea level doubtless played its role.

Underlying these Recent deposits—and also extensively developed as surface exposures west of Najaf—are gravel beds comprising quartz, flint, and limestone fragments of gravel and pebble size, usually partially embedded in a sandy, clayey, or gypsiferous matrix. These lie on an eroded surface of U. Fars (U. Miocene), and therefore are younger. The gravel beds in places bear a strong lithological and physical similarity to some Dibdibba exposures

further south. The age of the latter is not precisely known (probably it is Pliocene) and no fossils have so far been found in the gravels, but the possibility of correlating the two is tempting.

Should further work substantiate these findings and suggestions, then we may postulate Recent marine transgression extending as far as the Najaf area—almost halfway up the present delta.

ALWIYAH CLUB,
BAGHDAD, IRAQ.
28th November, 1957.

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RAOUL C. MITCHELL.

NAMURIAN STAGE NAMES

SIR,—In a recent paper Dr. F. Hodson (1957) has most usefully discussed and correlated the various faunal bands occurring in the West European Namurian in the lower part (R_1a) of the Kinderscoutian Stage and the upper part (Ha) of the Sabdenian Stage, and redescribed and figured some of the goniatites that occur therein. He has also proposed the replacement of the well-established Namurian stage Sabdenian (*Homoceras* Age, H) by two stages: an upper one which he equates with the *Homoceras eostriolatum* zone (Hb), the upper zone of the Sabdenian, and names Alportian; and a lower one which he equates with the *H. beyrichianum* zone (Ha), the lower zone of the Sabdenian, and names Chokierian. The stage names used for the Namurian before the publication of Dr. Hodson's paper have been accepted and widely used since their erection in their current form by Hudson and Cotton (1943). If chaos is to be avoided, changes in the nomenclature of stages should only be accepted for the most cogent of reasons, and it is, therefore, surprising to find that no reasons for his proposed changes are given by Dr. Hodson in his paper.

The name Sabdenian (founded Bisat, 1928, p. 126; redefined Hudson and Cotton, 1943, p. 152) was based on the formation Sabden Shales. The type section of the upper part of the *Homoceras* age was chosen by Bisat (1924, p. 49) as that exposed at Roughlee, east of Pendle Hill, Lancashire. There in the upper part of the Sabden Shales all the faunal bands typical of the upper zone (Hb) of the Sabdenian are exposed (Bisat, 1924, p. 49; Bisat and Hudson, 1943, p. 399; Hodson, 1957, p. 14). The change in the name of the upper part of the Sabdenian to Alportian also carries the implication that rocks of this age are well exposed at Alport in Derbyshire, which will become the typical sections for beds of this age. The exposures in Alport Dale, however, are incontestably worse than those at Roughlee.

There may be better reasons for using sections in the Assise de Chokier as typical of the lower part of the Sabdenian, but even in this case the biostratigraphical succession can be demonstrated in the Sabden Shales in Lancashire, and a change seems unnecessary.

It therefore seems to us that Dr. Hodson's proposed changes are unnecessary and even retrograde, and that the Sabdenian should be retained as a stage name within the Namurian.

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R. G. S. HUDSON,
IRAK PETROLEUM CO., LTD.,
214 OXFORD STREET,
LONDON, W. 1.

W. H. C. RAMSBOTTOM,
GEOLOGICAL SURVEY AND MUSEUM,
EXHIBITION ROAD,
LONDON, S.W. 7.

21st January, 1958.

REVIEWS

GLACIAL AND PLEISTOCENE GEOLOGY. By R. F. FLINT. xiii + 553 pp., 138 figs., 5 pls., 51 tables. John Wiley and Sons, Inc., New York, 1957. (Chapman and Hall, Ltd., London.) Price £5.

In his preface Professor Flint says that this book began as a revision of his *Glacial Geology and the Pleistocene Epoch*, published in 1947, but that the vast amount of work done on the subject since that time necessitated a new book rather than a mere revision.

The book can indeed be regarded as new. Much material has been added, on C^{14} chronology and "O^{18} temperatures", on pollen-analysis, soils, frozen-ground phenomena, and many other topics. Much must also have been removed, for the book is shorter than its predecessor by thirty-six pages, but this seems to have achieved more by general condensation than by the removal of entire passages. In addition, there have been extensive rearrangements. The most important are in the chapters on glaciology, which have been largely rewritten in an attempt to make them "more meaningful in glacial geology"; particularly useful here are special studies of the Greenland and Antarctic ice-sheets, included for the light they may throw on former ice-sheets elsewhere. In all parts of the book material has been shifted about in the interests of a more logical arrangement, and few individual sentences survive without alterations, if only to their punctuation.

These changes seem to be entirely successful. It need only be added that the book retains all the admirable stylistic qualities of Flint (1947): clarity, conciseness, and absence of unnecessary jargon ("hypsithermal" may be unlovely but is certainly not unnecessary). One hopes that Professor Flint will feel obliged to publish a similar volume in 1967.

R. W. H.

MIO-PLIOCENE FLORAS FROM WEST-CENTRAL NEVADA. By DANIEL I. AXELROD. University of California Publications in Geological Sciences, 33, 1–322, pls. 32, 18 figs. Univ. Calif. Press (Berkeley and Los Angeles), 1956. Price $7.50.

Included in this work are full descriptions and ecological discussions of four new floras, with geological maps by the author of the mainly pyroclastic rocks of the immediate surroundings of the localities. An analysis and comparison of these floras leads to the presentation of a Mio-Pliocene annual rainfall map for Nevada. Consideration of eighty-five other Tertiary floras culminates in a folded coloured palaeogeographic map showing distribution pattern of topography, vegetation, and climate of the whole Far West for the Mio-Pliocene. Interpretation, which is lavishly illustrated, is thus deliberately carried to great lengths; this is considered by the author as an essential preliminary to determination of the age of Tertiary floras.

The author reaffirms his view " that estimates of age must be based on the stage of evolution of floral elements and that all species in each floral unit have equal value in age indication ". It is unfortunate that so many palaeobotanists and others have allowed themselves to deny any detectable evolution in plants, and this refreshing antidote is most welcome; it perhaps follows from the amount of geological field work carried out by the author.

The floras consist essentially of leaf impressions and a few seed impressions. The whole work is of great value as a comprehensive statement apart from the new descriptions involved.

N. F. H.

FOSSILIUM CATALOGUS II: PLANTAE. Ed. W. JONGMANS. Parts 30, 31, and 32, Filicales, Pteridospermae, Cycadales, 3–5, by W. Jongmans, pp. 89–178, 179–246, and 247–366. W. Junk, s'Gravenhage, 1957. Prices f.27.50 (30), f.23.00 (31), f.37.50 (32).

Part 30 is the third of a long series covering alphabetically the Filicales, Pteridospermae, and Cycadales; it includes the complete record of the use of the genus *Alethopteris* and makes full reference to such recent works as Crookall (1955) and Doubinger (1956). Comment is made even on unnamed species and as with all fossil plants a starting point is taken about 1820, in this case with Sternberg (1825). Part 31 carries the work as far as *Anomorrhea* and Part 32 as far as *Azolla* inclusive. All names are treated as natural taxa, but this is normal practice in palaeobotany The compilation is in the German language although it makes little difference in this kind of work.

It is to be hoped that this most valuable record will be continued in spite of the death in October, 1957, of Professor Jongmans who was not only editor but author of this present series. It would make possible many further lines of progress in a subject which has a literature out of proportion to its current importance. Part 31 contains a photograph of Professor Jongmans and an appreciation of him by Dr. A. A. Thiadens, present director of the Geological Bureau at Heerlen; Dr. Thiadens concludes by saying that the Bureau, which holds the manuscripts, will make every effort to continue producing parts in this series for publication.

N. F. H.

A TREATISE ON LIMNOLOGY. Vol. 1, Geography, Physics, and Chemistry. By G. E. HUTCHINSON. John Wiley (Chapman and Hall, London), pp. xiv + 1015, with 228 figs. and 132 tables, 1957. Price £7 16*s*.

In the author's own words, " the aim of this book is to give as complete an account as is possible of the events characteristically occurring in lakes. The author, by training a biologist, is by inclination a naturalist who has tried to examine the whole sequence of geological, physical, chemical, and biological events that operate together in a lake basin."

All aspects of the physics and chemistry of lake waters are treated in very great detail in the present volume, and the complete work will obviously be on a much grander scale than Halbfass's *Grundzüge einer vergleichenden Seekunde*, which is now practically unobtainable.

Although students of sedimentation will await the second part of this work for a detailed treatment of lake deposits, there is much in the volume under review that is relevant to the study of sedimentary processes in lakes. The chapter on carbon dioxide and hydrogen ion concentration contains a useful discussion of calcium carbonate equilibrium in fresh water, and later chapters dealing with iron, phosphorus, silica, and sulphur include much information about the distrubution of these elements in lakes, and the processes that lead to the deposition of their compounds on the bottom.

To a geomorphologist, the principal interest is in the first chapter, which devotes 163 pages to the origin of lake basins. The treatment is very full, with detailed and well documented descriptions of a large number of examples, and ends with a formal classification which recognizes seventy-six different types of lake basin.

M. B.

LEHRBUCH DER TEKTONISCHEN GEOLOGIE. By KARL METZ. 1957. Ferdinand Enke, Stuttgart, pp. 294 + 188 text-figs. and 2 plates. Price DM. 46

This work covers the same general field as do several others on structural geology of about this price. It is divided into two parts distinguished by the scale of structure, namely the deformation of rocks and the development of the earth's crust.

This is essentially a textbook summarizing and selecting from a variety of sources, and recent as well as traditional material has been extensively used. At the same time much material has been compressed into relatively little space and, in contrast to some others that have grown by the greedy accumulation of definitions and the collection of miscellaneous hypotheses, this work gains by a thorough digestion and concise expression. Indeed, a consistently logical approach has been adopted with the elimination of much that is inessential and a corresponding emphasis on fundamentals. This deprives the reviewer of the opportunity of briefly summarizing the book in terms of a dozen or more familiar topics. Thus, for instance, consideration of fabric, symmetry, and movement patterns is not simply added as an extra chapter, but recurs in the discussion of the various basic rock structures. At a global level too the author, in reviewing current geotectonic ideas, takes the trouble to compare hypotheses of equivalent status and function and not simply juxtapose those with similar subject matter.

This is a compact and valuable treatise for advanced students and the principal drawback for so many of us is the language barrier. However, as is to be expected in a textbook arising out of a distinctive tradition and region, the selected topics and examples provide a refreshing alternative to what is in circulation elsewhere.

W. B. H.